European Commission

SOIL ATLAS OF AFRICA

Joint Research Centre

European Commission

SOIL ATLAS OF
AFRICA

A collaborative initiative of the European Union, the African Union and the Food and Agriculture Organization of the United Nations to support and encourage the sustainable use of soil resources in Africa and the Global Soil Partnership for Food Security.

FIAT PANIS

ESBN
European Soil Bureau Network

Joint Research Centre

Africa Soil Science Society
ASSS

ISRIC World Soil Information

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Cover

The striking map on the cover depicts the diversity of soil types across Africa according to the World Reference Base for Soil Resources classification and correlation scheme.

The central, more humid part of the continent is dominated by deeply weathered, acidic soils with high levels of iron oxides and lacking in essential plant nutrients (brown-orange are Ferralsols, often associated with Acrisols, light orange). In drier conditions, weathering processes are less intense which, together with inputs of wind-blown dust, give rise to soils with increased clay content and slightly higher pH (Lixisols appear as pale pink areas). In West Africa large areas are characterised by soils with surface layers hardened by iron and clay compounds, often leading to an inversion of the landscape (Plinthosols are shown by the dark brown colour).

The desert regions in the north and the south are dominated by soils that are lime-rich (bright yellow: Calcisols), shallow (grey: Leptosols), weakly developed (pale rose: Regosols), sandy (brownish yellow: Arenosols) and gypsum-rich (pale yellow: Gypsisols). In the dry part of southern Africa, soils with a significant accumulation of silica and an associated 'hardpan' can be found (pinkish grey: Durisols).

The dark purple colour on the map, notable in Sudan and Ethiopia, indicate soils containing high levels of swelling and shrinking clays (Vertisols) whereas the bright red colours depict associated with volcanic deposits (Andosols), especially evident along the African Rift Valley. This is also where most of Africa's most fertile soils are found (dark rose: Nitisols). In the Mediterranean region the pale brown and light green colours indicate soils that have developed under permanent grasslands (respectively, Kastanozems and Phaeozems).

Soils that are have been strongly influenced by water are found throughout the map and indicate wet conditions caused by high groundwater levels (dark blue: Gleysols), stagnant water (dark orange: Planosols) or sediments associated with Africa's river systems, deltas or mangroves (bright blue: Fluvisols). Saline and sodium-rich soils (purple: Solonchaks; light purple: Solonetz) are mainly associated with ephemeral lakes in arid climates and coastal plains.

Soils that are young in age and weakly developed (orange: Cambisols) or rich in organic matter (dark grey: Histosols) are scattered throughout the map. Soils such as Luvisols (dark pink), Podzols (green) and Umbrisols (dark green) can be locally important. In urbanized areas and near large mines, highly disturbed soils (Technosols) may occur. However, they are too small to be visible given the small scale of this map.

Cartographic Representations

Underlying cartographic features depicted on the maps in this atlas are derived from the Digital Chart of the World and Lovell Johns Cartographic Base. These data do not have any explicit legal status; hence, no legal aspects should be derived from the information depicted on any of the maps in this publication.

http://en.wikipedia.org/wiki/Digital_Chart_of_the_World

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Soil Data

The soil maps presented in this atlas are derived from several projects covering the African continent. They include:

- The Harmonized World Soil Database
- The Soil Geographical Database of Eurasia (scale 1:1 000 000)
- The FAO-UNESCO 1:5 000 000 Soil map of the World

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- FAO/IIASA/ISRIC/ISSCAS/JRC, 2009. Harmonized World Soil Database (version 1.1). FAO, Rome, Italy and IIASA, Laxenburg, Austria.

    http://www.iiasa.ac.at/

- Van Liedekerke, M., Panagos, P., Daroussin, J., Jones, R., Jones, A. & Montanarella, L., 2004. The European Soil Database Version 2.0. Distributed by the European Commission Joint Research Centre, Ispra, Italy

    http://eusoils.jrc.ec.europa.eu/

- FAO - UNESCO, 1974. Soil Map of the World, 1:5.000.000

    http://www.fao.org/

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The EU supports the efforts by the Secretary General of the United Nations and his Personal Envoy to find a just, lasting and mutually acceptable political solution which will allow the self-determination of the people of the Western Sahara as provided for in the resolutions of the United Nations.

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Some members of the Editorial Board in Cameroon during the 2009 Africa Soil Science Society Conference.

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[†] Regrettably, Peter Bullock, an enthusiastic supporter of the atlas project and an experienced authority on the soils of Africa, passed away during the early stages of this publication, to which he willingly gave much valuable material and direction. An active researcher and an excellent scientist, his enthusiastic contributions are sorely missed.

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[††] Regrettably passed away before the publication of the atlas.

CONTENTS

Soil, along with water, is arguably the most precious resource on the planet. In addition to the widely recognised agricultural benefits, soil also provides a myriad of life-critical environmental services that are fundamental to the well-being of all creatures on the planet. This picture from the Ubari Desert of Libya shows an oasis in the lee of a large dune complex in a sand desert. Oases are isolated areas of vegetation in arid areas surrounding a water source, normally a spring or a well to an underground aquifer. The combination of water, organic matter from plant remains, animal manure and the soil provides the necessary conditions for vegetation to survive and flourish in an otherwise hostile environment. If properly managed, oases soils can support a large variety of plants and crops. Soils in oases are often raised due to the addition of organic matter and irrigation water containing substantial amounts of sediments. (TS)

In contrast to the desert landscape from Libya, this photograph shows a lush, verdant environment on volcanic deposits along the Rift Valley in Tanzania. It is clear that the soil characteristics here will be very different to those in the desert. Throughout Africa, rural populations depend on soil functions to provide food for their families, fodder for animals, fuel for cooking, crops for markets – activities that are fundamental to the economies of most African countries – and even the walls of their homes. Plants such as tea, coffee, cocoa, oil palm, cotton, sugar cane, bananas, oranges and olives are often referred to as 'cash crops' because of their high economic value. Mono-culture (i.e. the continued cultivation of a single crop) will in time lead to a reduction in soil fertility and the onset of land degradation issues such as erosion. Recent interest in the development of biofuels as an alternative source of energy is putting many soils in Africa under increased pressure. (VL)

Preface

The sustainable management of natural resources in Africa is a formidable challenge, crucial for the survival of over one billion people. Africa has the capacity to feed itself, and its soil has maintained its fertility over millennia. Throughout the continent, many areas now suffer from land degradation from inappropriate cultivation practices which are often driven by a desire for quick economic return, but ignore the capacity of the soil to support them, exacerbated by a high level of rural poverty.

Understanding the evolution of soils and associated vegetation patterns in relation to their use by society is fundamental if we wish to assess fully the impacts of processes driving change in Africa. This applies equally to climate change, population growth and food security, which are key challenges that EU policies seek to address through numerous initiatives.

The evidence for soil degradation and environmental change is apparent in many parts of Africa. By building on existing cooperation with researchers from Africa, EU Member States and international organisations, the European Commission's in house science service, the Joint Research Centre (JRC), brings together people from diverse national and political backgrounds to address this relevant issue, and communicate science to the wider society.

This innovative "Soil Atlas of Africa" aims to raise public awareness on the importance and the key role of soil in Africa as a non-renewable resource essential to human existence. In doing so, it supports the development of protective measures to safeguard soils for current and future generations.

The atlas compiles existing information on different soil types in easily understandable maps that cover the entire African continent. While it is intended primarily for the educational sectors and policy makers, the atlas aims to bridge the gap between soil science and society at large.

We believe that this impressive publication will become a widely-used reference and marks an important step towards a better understanding of the role of soil in the sustainable development of Africa.

Máire Geoghegan-Quinn

EU Commissioner
Research, Innovation and Science

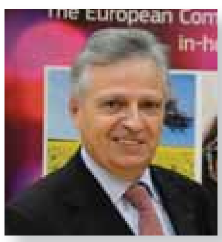
Andris Piebalgs

EU Commissioner
Development

In its role as the only Commission service performing direct research in support of European policies, the Joint Research Centre (JRC) has undertaken the task to collect and compile a dataset about soils worldwide. This "Soil Atlas of Africa" is a significant step forward in this effort.

Resulting from a fruitful partnership of leading African and European scientific experts in soil research, the issue complements a series of other atlases developed in recent years: Soil Atlas of Europe, Soil Atlas of the Northern Circumpolar Region, European Atlas of Soil Biodiversity, and the forthcoming Soil Atlas of Latin America and the Caribbean.

One of the main outcomes of JRC's long term engagement in soil research concerns the acknowledgement of the strategic importance of soils for all nations, especially in face of the current global economic, social and environmental challenges. All these aspects are included in the atlas in clear and accessible language, completely illustrated with diagrams and many maps. I am pleased to endorse this atlas, which demonstrates that a wealth of scientific information can be disclosed in a very interesting way.



Dominique Ristori

Director-General
European Commission DG Joint Research Centre

Foreword

Although it is all around us, soil is often the most overlooked natural resource. We know that, depending on the region, it can take one hundred to one thousand years to form just one centimetre of soil. And yet, degradation and erosion can lead to the loss of that precious soil in few minutes.

Recognizing that soils are the foundation of agriculture and food production, and thus one of the main pillars of food security, FAO has played a lead role over the years in developing tools and providing technical and policy support for soils and land resources information and sustainable management in Africa.

The Soil Fertility Initiative with the World Bank in the '90s raised attention of countries in Sub-Saharan Africa to the need for integrated soil policy for sustainable agriculture. However, soils have not been a priority area in the decision making agenda for many years. Why is this? It seems that soil is a "hidden resource" and few decision-makers are really aware of its key role in the provision of ecosystem goods and services.

Strategies to address sustainable management of soils and the preservation of this resource for future generations need to be scientifically sound and based on the most current data. For its part, the FAO, together with the African Union and the European Commission, will continue to promote awareness raising events, soils data and information, research projects to fill knowledge gaps and address real problems on the ground, technical support and capacity development in particular to mentor young soil scientists and the integration of soil related issues into policy decisions for agricultural development and food security Agenda in Africa.

This striking, informative and timely document perfectly supports the ideals of the FAO led Global Soil Partnership. I hope that you will find this Atlas both enlightening and useful as a scientific reference and as general source of information about the immense variety of African soils and their vital functions.

Prof. José Graziano da Silva

Director-General
United Nations Food and Agriculture Organisation

Key messages

To ensure the sustainable use of soil resources, the people of Africa should strive to:

- assess the current state of soils and associated pressures across their territories;
- assess the impacts of current policies and land use practices on soil quality in areas such as agriculture, waste, urban development or mining, and to adopt preventative measures to ensure the sustainable use of soil and maintenance of soil functions and services;
- develop action programmes to deal with the main issues of local concern, including strategies for the remediation of degraded and contaminated land;
- develop systems for the collection of harmonised soil information and long-term monitoring of trends in soil functions and characteristics;
- support the networking of soil scientists and land use experts from across Africa in order to improve information exchange and develop a more comprehensive knowledge-base to underpin sustainable soil use policy development and practices;
- develop awareness raising strategies to highlight the importance of soil to everyday life and thus promote the good management of soil for future generations.

Preamble

Healthy, fertile soils underpin food security, social cohesion and the economies of most African countries. Unfortunately, soil tends only to reach public consciousness when it fails – often with catastrophic consequences as seen by the famine episodes of the Sahel in the 1980s and more recently in Niger and the Horn of Africa. While large parts of the continent are hot and arid, in reality, Africa has some of the most fertile soils on the planet. However, conflicting or competing demands on the use of the land is putting increasing pressures on what remains.

This atlas, the result of collaboration between African and European scientists outlines the specific challenges facing soil resources across Africa. By highlighting the factors that control specific ecological, agricultural and economic services, the atlas highlights the need for a coherent and holistic approach to the management of soil across the continent.

I hope you enjoy this beautiful book.

Tumusiime Rhoda Peace

AU Commissioner
Rural Economy and Agriculture

Message from the Africa Soil Science Society

If asked to consider the question of what they know about soil in Africa, the vast majority of people have no idea how to answer. For many, the first thoughts that spring to mind are scenes of dusty, infertile land, accompanied by images of people suffering from drought and famine. Further reflection may bring to mind images of hot and humid rainforests with dense, lush vegetation growing on bright red tropical soils. In reality, soils on the African continent can be productive, are highly diverse and, in many cases unique. Healthy soils underpin so many vital services. Of these, one could argue that food production is the most critical as it is basic to human survival. Yet where would we be without the myriad of other soil functions – a rooting medium for plants (hence the main source of food, fibre and fuel on the planet), water storage, the preservation of our cultural heritage, and so on.

Averting soil degradation in Africa is a major challenge. Across the continent, annual soil losses are estimated to be in the order of hundreds of millions of tonnes. The population explosion, rapid urban expansion, increased pressure on existing agricultural areas, and the short-term financial gains made through overstocking, mono-cropping and the ploughing of marginal lands unsuitable for cultivation are all drivers of land degradation. Such practices encourage the exploitation of the land without due regard to the long-term consequences.

When erosion by wind or water removes the nutrient-rich topsoil, cultivation becomes increasingly difficult. When this occurs in areas where people are too poor to replace the loss with fertiliser, soil fertility slowly declines and yields fall, driving farmers deeper into poverty. If left unattended, the result can be catastrophic, not just for the land but also for the populations that depend on the soil for their wellbeing and livelihood. For these reasons, understanding the importance of the proper and sustainable management of soil should be a crucial goal for society as a whole. Political and economic changes are needed to address soil use and management throughout Africa. The Soil Atlas of Africa represents a consolidated effort to raise awareness about the value of this key resource. Finally, this Atlas would certainly not have been produced without the scientific heritage that was left by the many European soil scientists who travelled to Africa.

Dr. Martin Yemefack

President
Africa Soil Science Society

Dr. Robert Zougmoré

Secretary-General
Africa Soil Science Society

Dr. Lamourdia Thiombiano

FAO Deputy Regional
Representative for Africa

A general perception of tropical Africa is probably one of lush rainforests growing on red soils (as shown by this striking profile from Tanzania). Most soils in the tropics are actually deeply weathered (which indicates that they are very old), highly acidic and largely devoid of essential nutrients (such as phosphorus, potassium, calcium and magnesium) which have been leached out over time. They contain high levels of iron oxides which give rise to their distinctive reddish or yellowish colour. Natural ecosystems have evolved to survive in such poor soils by maintaining a fragile nutrient cycle that exploits a unique relationship between the rapid decay of litter, the roots of plants and a type of fungus called mycorrhiza. Clearing the forest destroys this balance, causing the soil to become infertile within a few years. (EM)

Soils underpin the classical landscapes of Africa which, in turn, reflect the principle soil forming factors of parent material, climate, topography, vegetation (itself driven by the chemical and physical properties of the soil), time and the influence of human beings. The photograph shows giraffes (*Giraffa camelopardalis*) grazing on Acacia trees (also known as thorntrees) on the Rift Valley floor in east Africa. Acacias can tolerate many soil condition, even dry, well-drained, lime-free soils. Once established, vegetation provides organic matter to the soil and, in some cases, shade for other plants to flourish, especially in dry or hot climates. Where soil moisture is low or lacking, the roots of plants such as Acacias can extend for up to 30 m below the surface. As a member of the pea family, most Acacia trees are able to take nitrogen from the air and store it in the soil. (EM)

Scope of the atlas

Soil, a material composed of minerals, organic material, air and water, performs a number of key environmental, social and economic services that are vital to life. Supplying water and nutrients to plants, at the same time soil protects water supplies by storing, buffering and transforming pollutants. Soil is also an incredible habitat that provides raw materials, preserves our history and reduces the risk of floods. Without soil, the planet as we know it would not function.

However, the importance of soil and the multitude of environmental services that depend on soil properties are not widely understood by society at large. A part of the problem is that with an increasingly urban society, many people have lost contact with the processes that produce food. Most people expect to find food on the shelves of supermarkets and have limited or even no appreciation of the roles played by soil. Concepts such as nutrient cycling and organic matter management, that are critical to soil fertility and food production, are a mystery to most. To compound matters, there is very little dialogue between the soil science community and the general public. The majority of soil-related print material is geared towards university level or scientific journals - normally beyond the reach and understanding of the general public. This results in a lack of material to help interested stakeholders appreciate the value of soil and guide them in preserving this precious resource.

As a consequence, soil as a topic tends not to feature in the minds of the public or politicians. However, some groups are becoming increasingly aware of a greater need to inform and educate the general public, policy makers, land managers and other scientists of the importance and global significance of soil. This is particularly true of the soils in Africa where the dramatic consequences of the failure to use soil sustainably have led to desertification, famine, civil unrest and human suffering, often on astonishingly large scales.

Soil is the interface between the hydrosphere, atmosphere, lithosphere and organisms inhabiting it. Consequently, the structure and other characteristics of soil are the products of age-old processes. As the regulator of biogeochemical and energy cycles, soil is extremely sensitive to the effects of climate change and to human activities. Such changes can have dramatic consequences on one of the key services provided by soil - the provision of food, fibre and fuel. This striking photograph of Mt. Kilimanjaro, Africa's highest mountain, shows the several aspects of soil. In the foreground, the soil is being used for agriculture under a plantation farming system. This aspect provides for the production of food and underpins the economy of many African countries. In the middle ground, the soil supports semi-natural vegetation and a host of ecological services such as biodiversity and nutrient cycling. In the background, the receding glaciers are a clear indication of a changing climatic conditions, which in turn, will affect the surrounding soils. (WS)

It is in these contexts that the European Commission's Joint Research Centre initiated a project to bring together experts from Europe and Africa to produce the **first** ever **SOIL ATLAS OF AFRICA**. The main goal of the project was to produce a publication, aimed at the general public, decision makers, politicians, teachers and even scientists in other disciplines, that raises awareness of the significance of soil to human existence in Africa.

The preservation of organic matter is a precondition for a soil to undertake many of its key environmental services, especially that of supporting agriculture. In this photograph from North Africa, the dark colour of the soil indicates a high level of organic matter, usually as a result of a permanent cover of grass and a climate where the soil is moist for most of the year. Such soils are valued for their agricultural productivity, in particular cereals, such as wheat and barley, or vegetables. However, the characteristics that make the soil favourable for agriculture should be managed by timely cultivation and careful use of irrigation, if required. In Africa, such soils are limited in their extent. In the humid tropics, most soils are highly leached and low in organic matter. Traditional shifting cultivation practices, where land was abandoned after a few years of cultivation, allowed organic matter levels in soils to recover during sufficiently long fallow periods. However, modern sedentary farming methods on such soils require constant fertilisation and specific management practices to achieve satisfactory yields. (GT)

The atlas attempts to show and explain in a simple and clear manner the reasons for the varying patterns of soil across Africa as well as the need to conserve and manage this increasingly threatened natural resource through sustainable use. At its heart is a series of annotated maps that show, for the very first time, the diversity of soil characteristics across the African continent in a manner that is comprehensible to the layperson.

The atlas explains in a non-technical manner how soils are formed, the key factors that shape soil characteristics and why these vary across the African continent. Special attention is given to the pressures on the soil of Africa through illustrated examples.

Furthermore, the atlas supports the goals of the European Union's Thematic Strategy for Soil Protection [1,1a] and the Sustainable Use of Natural Resources [2]. The atlas is a practical example of the aims of the joint Africa-EU Strategic Partnership, especially in the context of sustainable environmental development [3] while being a major contribution of the EU to the United Nations Food and Agriculture Organization's Global Soil Partnership initiative [4].

Red is the dominant colour of soils in tropical Africa. While soil colour can vary dramatically throughout the continent, the long-term weathering of iron-rich sediments, especially in the tropics, does produce striking red and yellow colourations of the soil. This picture shows villagers looking at a red, fertile soil that has developed from the nutrient-rich weathering products of basaltic rocks found on the southern slopes of Mount Kilimanjaro in Tanzania. (EM)

After reading this atlas, we hope that the content helps you to understand better how the product of the complex interactions between climate, the landscape, the geological substrate, vegetation, living organisms, human influences and time leads to the creation of the valuable resource we call soil.

Key facts about soil

- A sample of mineral soil consists of (by mass) minerals (up to 95%), water (15-35%), air (15-35%) and organic matter (5%). In arid regions, the amount of water and organic matter will be much less.
- Some soils in Africa can be very old – often reflecting dramatic changes in climate and vegetation.
- Many soils in Africa are red in colour indicating high levels of iron or aluminium oxides.
- More than half of the African land surface is characterised by sandy soils (22%), shallow stony soils (17%) and young, weakly developed soils (11%).
- Unlike other continents, the area of peat soils is very small in Africa.
- In some temperate ecosystems, 5 tonnes of living organisms (or the equivalent of one elephant) can be found in one hectare of soil – most of which still needs to be studied.
- Soil reduces the risk of floods and protects underground water supplies. Soil organic matter can store more than ten times its weight of water.
- The soils of Africa store about 200 Gt of organic carbon - about 2.5 times the amount contained in the plant communities of the continent.
- One of the most important functions of soil is the recycling of nitrogen, phosphorus, carbon and other nutrients. The harvesting of crops from cultivated soils breaks the nutrient cycle, which then requires additional inputs. In many parts of Africa, soils are losing nutrients at a very high rate, much greater than the levels of fertiliser inputs.
- Soils under tropical rainforests are not naturally fertile but depend instead on the high and constant supply of organic matter from natural vegetation. Breaking this cycle (i.e. through deforestation) quickly reduces the productivity of the soil.
- The largest earthworm ever found was discovered in 1967 in Williamstown, South Africa and measured 6.7 metres in length.
- 98% of all calories consumed in African comes from the soil.
- Soil degradation (e.g. erosion, chemical and physical damage) affects about 65% of African farmlands.

The role and importance of soil

Soil is the vital natural habitat that regulates our environment and responds to the pressures imposed upon it. Ignored by the majority of us, soil carries out a number of key tasks that are essential to our well-being:

Soil is the medium that enables us to grow our food, natural fibre and timber and supports wildlife habitats

One of the most widely recognised functions of soil is as the material in which plants grow. In turn, many of these plants are used by people directly as food (i.e. crops) or medicines, as feed for animals or for fibre (e.g. for fuel or construction). Food security is a key issue in Africa. While many areas have naturally productive soils, many African farmers traditionally maintained soil fertility by practising shifting cultivation or applying mineral fertilisers on their fields. However, economic and social conditions in recent years have seen a decline in both traditional shifting agriculture systems and access to subsidised agro-chemicals. Additionally, many soils in Africa have severe limitations for growing crops because they are too shallow, too wet, too dry or lacking in nutrients. Extreme climate zones mean that biological activity and the availability of essential nutrients in the soil vary significantly. In hot, dry regions, the most productive agricultural soils are to be found along the major river valleys or around wells or oases.

Soil is a natural filter and regulator of water flow

One of the key functions of soil is to act as a natural purification system. Over time, soil has the ability to filter, absorb and transform substances. Chemical compounds that are deposited on or in the soil, together with excess agro-chemicals, can be trapped, thus preventing them from reaching clean water supplies. Additionally, contaminates can be degraded or otherwise made unavailable to plants and animals through a range of biogeochemical processes. However, high levels of toxins or severe soil degradation can disrupt these processes leading to a loss of this function.

Soil is also a key regulator of water flow. Soil can absorb much of the rain that falls on it, but the amount varies according to texture, structure, organic matter content and vegetation cover. Well structured loamy soil under grass or woodland acts like a sponge and can absorb as much as 40% of its volume as water. Soil also acts like a tap, turning water flow on and off by storing and releasing water for plants when needed. Urban planners now realise that the sealing of soil by materials such as concrete and asphalt, together with compaction of the subsoil, is a significant factor in exacerbating the risk of floods from heavy rainfall. Any reduction in the capacity of soil to absorb water will lead to increased overland flow, the rapid transfer of rainfall to river channels, flooding and erosion.

A lush meadow in South Africa growing on a clay-rich soil that typically develops in depressions or basins that are periodically wet. One of the main services provided by soil is in the provision of food, feed for animals, fibre for clothing and wood for fuel or construction. However, soil depletion and degradation are major issues which can lead to hunger and poverty in many parts of Sub-Saharan Africa. Since the 1970s, food production has not kept pace with population growth in Africa, which is now in excess of 1 billion people. Increased pressure on the land, a decline in soil fertility, and an acceleration of desertification in many places means that the soil is unable to meet expectations. Strategies for improving soil fertility include the use of compost, crop residues, animal manure, biomass, chipped wood, hedgerow intercropping (alley farming) and cover crops. In addition, natural grasslands such as this are an important store of carbon. (EM)

Soil and water

Infiltration is the physical process involving the movement of water through the soil surface, essentially the boundary between the atmosphere and the ground. The ability of water to enter the soil is related to its porosity (the amount of space within the soil) and permeability (the ability of liquids to flow through the soil). In turn, these factors are governed by the texture and structure of the soil, the initial soil moisture content, soil composition and the swelling of clay minerals that can cause cracks in the soil to close. Water that has infiltrated the soil can later be released through evapotranspiration or subsurface flow.

Percolation is the movement of water though the soil by gravity and capillary forces. Water that is in contact with air in the soil is called vadose water. Where the voids (pores) in the soil are full of water, this saturated zone is called groundwater. Groundwater can move in both vertical and horizontal directions. The boundary that separates the vadose and the saturation zones is called the water table.

A spring is a feature in the landscape where the water table reaches the surface. Groundwater discharges from the soil form the base flow of streams and rivers. This is especially important for maintaining a minimum level of water in channels during dry periods.

Lake Ubari, a brackish oasis in the Libyan desert (Erg Awbari) which, despite the saline water and encroaching dunes, supports extensive groves of palm trees. In recent years, the water table has dropped markedly in some of the lakes. Lake Mandara, once one of the biggest, is now almost dry. The drop in water level has been attributed to water diversion schemes. (BN)

Soil protects our buried heritage of archaeological and historic remains from damage and depletion

Much of the evidence of human heritage remains buried within the soil, awaiting discovery and study by archaeologists and palaeoecologists (scientists that study past environments and ecosystems). The degree of preservation of such remains depends very much on the local soil characteristics and conditions.

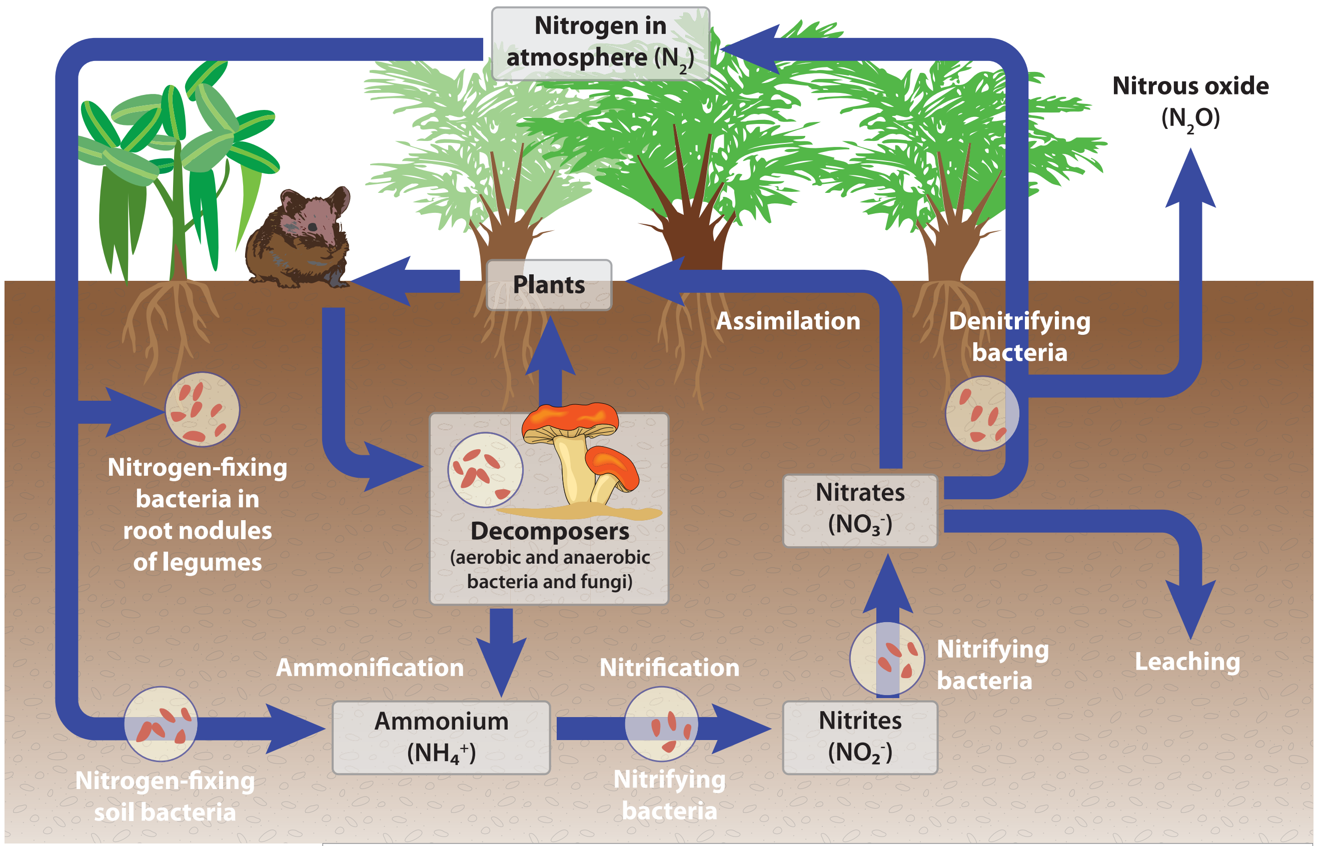
Soils with extreme characteristics (e.g very acid, very alkaline or waterlogged with low levels of oxygen) have very little microbial activity and provide an ideal environment for preserving organic remains. Any disturbance of these environments, such as by drainage or ploughing, changes these conditions and leads to the rapid decay and loss of the material. Archaeologists use these historical artefacts and the layers in which they are preserved to reconstruct the communities that produced them and the environments in which they lived. But to do this, the soil layers must remain undisturbed.

The occurrence of fossil soils (paleosols) and rock art across the Sahara provide clear evidence of dramatic fluctuations in climatic and environmental conditions. This carving of a cow comes from the Wadi Methkhandoush in Libya, a region that was once rich in lakes and rivers where such animals roamed the land (see also page 142). (TS)

Soil is the environmental engine room where dead plants, animal tissues and other organic matter remains are decomposed to recycle nutrients for the growth of new life

The decay of organic matter is driven by soil organisms, the total weight of which often equals or exceeds the above-ground biomass. A few hundred grammes of fertile soil can contain billions of bacteria, kilometres of fungal hyphae, tens of thousands of protozoa, thousands of nematodes, several hundred insects, arachnids and worms, and hundreds of metres of plant roots.

The biota turns the soil into a biological engine. Living creatures are involved in most of the key soil functions, driving fundamental nutrient cycling processes, regulating plant communities, degrading pollutants and helping to stabilise soil structure. Soil organisms also represent a crucially important biotechnological resource, with many species of bacteria and actinomycetes providing sources of antibiotics.



The nitrogen cycle in the soil-plant ecosystem. Bacteria in nodules on the roots of plants such as clover, alfalfa, and soybeans take nitrogen from the air and convert it into ammonium. This is then converted by other bacteria into nitrite ions and then into nitrate ions. Plants use the nitrate ions as a nutrients for growth. Other bacteria in the soil carry out a process known as denitrification which converts nitrates back to nitrogen gas. As well as being a greenhouse gas, nitrous oxide is also a mild anaesthetic known as 'laughing gas'. (LJ/EPA)

Soil provides the foundation upon which we construct our buildings, roads and other infrastructures

In addition to providing the support for the vast majority of human infrastructure, soil provides a range of raw materials such as clay, sands, minerals and peat. Clay is used for making bricks for construction, pottery items (e.g. earthenware) and was an early writing medium (clay tablets).

Daub is a building material that has been used for at least 6000 years for making the walls of buildings. A woven lattice of wooden strips is daubed with a sticky material usually made from wet soil, clay, sand, animal dung and straw. It is still an important construction material in many parts of Africa and the technique is becoming popular again as a low-impact, sustainable building technique.

Mud bricks, made of a mixture of clay, silt, sand and water mixed with a binding material such as rice husks or straw, are a common building material in countries such as Niger and Mali. Dried in the sun for 25 days, these bricks have a lifetime of some 30 years.

Due to its impermeable properties, clay is used as a barrier to stop water seeping away which is why many ponds, canals and landfill sites are lined with clay.

Sand and gravel deposits, laid down by rivers, are heavily used in the construction industry as aggregates in concrete making, while sand is the principal ingredient in glass making and is used in sand-blasting to clean buildings and in sandbags to stop flooding. Like sand, gravel has countless uses. For example, in Africa, more roads have gravel surfaces than concrete or asphalt.

While peat can be added to soil by gardeners to improve structure and enhance soil moisture retention, in some parts of Africa, peat is a source of fuel. Increasingly, people are becoming aware of the environmental impact of peat exploitation and are looking for 'peat-friendly' alternatives.

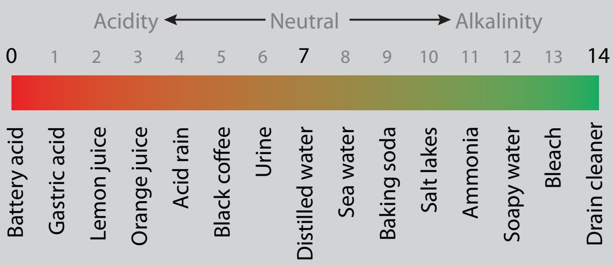
The Great Mosque of Djenné in Mali, is the largest mud brick structure in the world. The structure is built from thousands of sun-baked mud bricks (called ferey) and a mud-based mortar coated with a mud plaster. Massive walls (between 40 – 60 cm thick) bear the weight of the tall structure and provide insulation from the sun's heat. During the day, the walls gradually warm up from the outside and cool down at night. The mosque's prayer hall can contain up to 3000 people. The outside plaster is renewed every spring. (AG)

What is meant by heavy or light soil?

Soils are sometimes referred to as heavy or light. This is the ease with which they can be worked or tilled and depends on their texture (see box on page 12). Heavy soils contain greater proportions of clay or silt particles and retain much more moisture than soils with larger particles, such as sand. Consequently, they are heavier to dig into and turn over than light sandy soils.

What is pH?

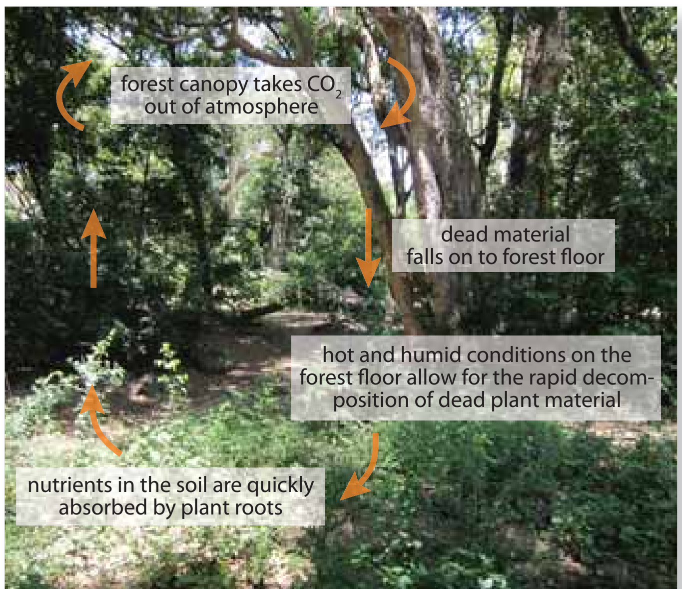
Soils are often described as being acid or alkaline or having a certain pH value. The pH scale (from 0 to 14) indicates the degree of acidity based on the concentration of hydrogen ions in a solution. Soils typically fall between pH4 to pH11, with a neutral soil having a pH of 7. Alkaline soils will have a pH greater than 7 while acid soils will have a pH below 7. The pH is usually measured by mixing a sample of soil with deionised water, KCl or $CaCl_2$.



Soil as a regulator of the biogeochemical cycles

Soil plays a crucial role in a number of life-sustaining natural biological and chemical cycles. Carbon, nitrogen (see above) and a range of essential nutrients are continuously recycled between the soil and plants, geological deposits, groundwater and the atmosphere. The intensity of these biogeochemical exchanges (fluxes) varies from place to place and is regulated by soil characteristics, land use and climate.

The graphic below demonstrates nutrient cycling in the rainforest. The hot, damp conditions on the forest floor allow for the rapid decomposition of dead plant material. This provides nutrients to the soil that are then easily absorbed by plant roots. However, as these nutrients are in high demand from the rainforest's lush vegetation, they do not remain in the soil for long. Therefore, more nutrients must be supplied. This rapid consumption means that nutrients in the soil are concentrated near the surface. If the forest vegetation is removed, the flow of nutrients from the vegetation to the soil is interrupted and the soils quickly lose their fertility so becoming vulnerable to erosion. The majority of cleared rainforest can only be used for agriculture if additional lime and fertiliser are added.



Nutrient cycle in tropical rainforests. The example in this photograph comes from near Arba Minch in South Ethiopia. (SD/JRC/LJ)

Soil the vital role

The soil functions described on these pages are vital to life on Earth. However, not all soil types can carry them out to the same extent and some are far more susceptible to failure when stresses are placed on them. A clear understanding of the functional capability and potential of different soil types is thus vital for planning and managing the sustainable development of African resources.

Trees growing in shallow and weakly developed soils in a semi-arid part of East Africa. Litter fall and the roots of the trees provide sufficient nutrients for other shrubs to flourish in their shade. In turn, soil organisms and larger mammals can survive. (EM)

What is soil?

The term 'soil' means different things to different people. To the vast majority living in cities and towns, soil is simply the 'dirt' or 'dust' to be cleaned from their hands or the vegetables that they buy to eat. However, to the gardener or farmer, soil is the uppermost 25 cm of ground that is cultivated and nurtured to produce crops. To the engineer, it is the 'overburden' or unwanted loose material at the ground surface that needs to be removed to provide a more stable foundation upon which to work. To the biologist, it is a fascinating habitat teeming with life. To the climate change modeller, it is both a storehouse and source of carbon and greenhouse gasses such as methane, carbon dioxide and nitrous oxide. To the hydrologist, soil is a buffer that stores rainfall, alleviating floods and providing drinking water as well as base flow for rivers.

In fact, soil is all of these things. Soil is the living, breathing skin of our planet. Soil is the result of the interactions between the atmosphere (as governed by climate), the biosphere (local vegetation, animal activities including those of man) and the geosphere (the rocks and sediments that form the upper few metres of the Earth's solid crust). Those of us who study soil have a definition for it. We say **'soil is any loose material at the surface of the Earth that is capable of supporting life'** and these life-supporting functions have been understood from the earliest of times.

"Essentially, all life depends upon the soil ... There can be no life without soil and no soil without life; they have evolved together."

Charles E. Kellogg (1938)

What is soil made of?

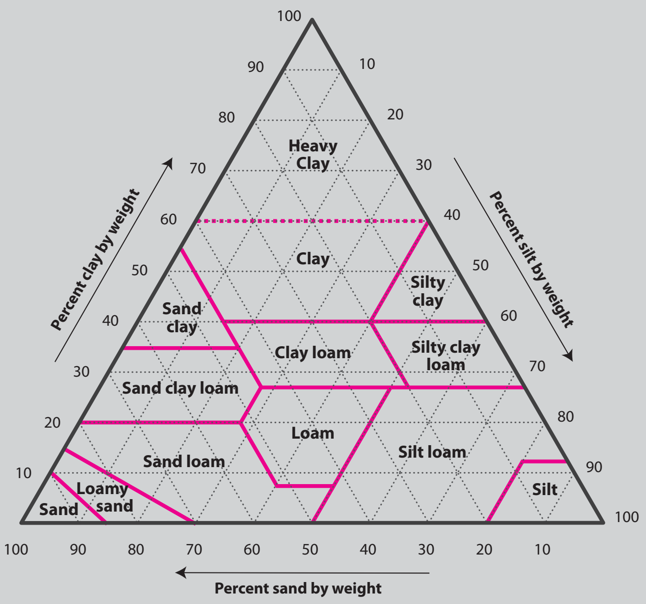
All of us have come into contact with soil at some time in our lives and most people are familiar with such terms as clay, silt, sand or peat. In reality, soil consists of a complex mixture of mineral and organic particles that represent the products of weathering and biochemical processes. Rocks are weathered into individual grains while the dead vegetation and organisms are transformed into soil organic matter.

When we handle soil, the fact that it usually stains and moistens our fingers, shows that it holds different amounts of water, organic compounds, minerals and chemicals.

Soil texture and structure

Texture describes the proportion of different sized mineral particles that are found in a soil. The main particle size classes are broadly clay (<0.002 mm), silt (0.02 – 0.63 mm) and sand (0.063 – 2.0 mm) [5]. Texture is measured by sieving or by feeling the grains by rubbing the soil between your fingers. Particle size classifications may vary in different countries. Furthermore, large sand particles can be described as coarse, medium and fine.

Structure refers to the natural arrangement of soil particles (also called aggregates) and the space between them. Soil structure thus has a major influence on the movement of water and air and root growth. Structure depends on factors such as the parent material, mineralogy, biological activity, environmental conditions, land management and the amount of clay and organic matter.



Soil texture triangle – soils can be categorized according to their texture following particle size analysis in a laboratory. Thus a soil with 40% sand, 40% silt and 20% clay fractions will be a loam. (FAO) [5]

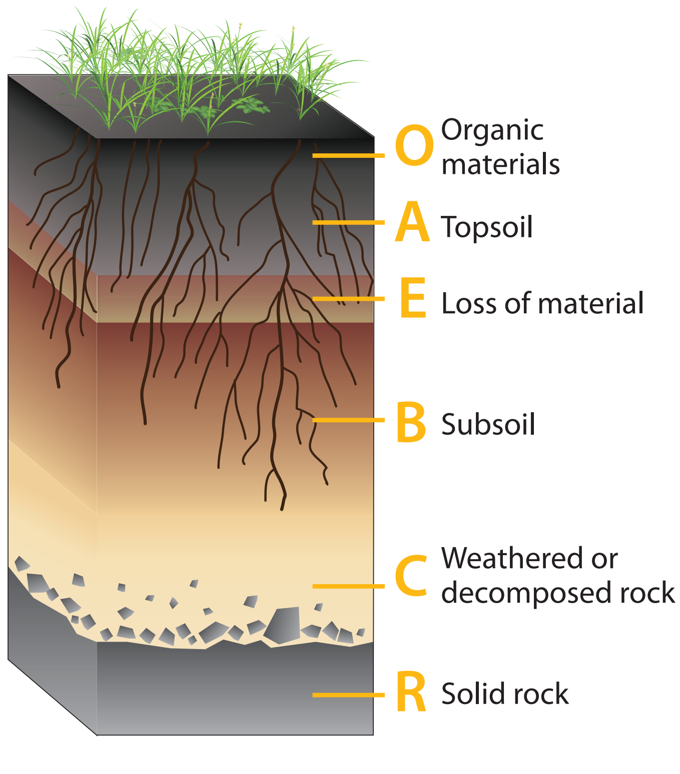
Unlike hard rock, pores and cracks in the soil contain 'soil air' with a higher concentration of carbon dioxide than exists in the Earth's atmosphere. The most important components that make up soil are the organisms, both plants and animals, that live (and die) within it.

The soil in profile

In most cases, if we dig a hole into the soil and look at the vertical section revealed, we will notice a number of different layers, roughly parallel to the surface. These layers are referred to as 'horizons' and are the result of a range of geological, chemical and biological processes that have acted upon the parent material over the lifetime of the soil. Relatively young soils, such as those on river sediments, sand dunes, or volcanic ash, may have indistinct or even no horizon formation. As age increases, horizons are generally more easily observed (there are exceptions such as in deeply weathered tropical or permafrost-affected soils).

Most soils usually exhibit three or four horizons (there can be more or less). Horizons are generally described by colour, texture, structure, organic matter and presence of carbonates. More detailed chemical characteristics can be measured in the laboratory. Some soils show a gradual change from one horizon to another while other soils may possess horizons that have markedly different characteristics to each other.

The identification and quantitative description of horizons are an important aspect of studying soils. Most soils conform to a similar general pattern of horizons and in soil science, major horizons are usually denoted by a capital letter as a means of shorthand and easy communication (typically followed by several alphanumerical characters to denote a characteristic feature). [5]



A hypothetical profile showing the main soil horizons and their relation to parent material, root development and soil-forming processes. The E horizon occurs in mineral soils when materials such as clay, iron and aluminium have been destroyed or flushed to deeper layers by percolating water. E horizons are usually lighter in colour (but not always) and have a coarser texture. Other possible horizon codes are L (sediments deposited in a body of water) and W (presence of water layers). (LJ)

Know Your A, B, C...

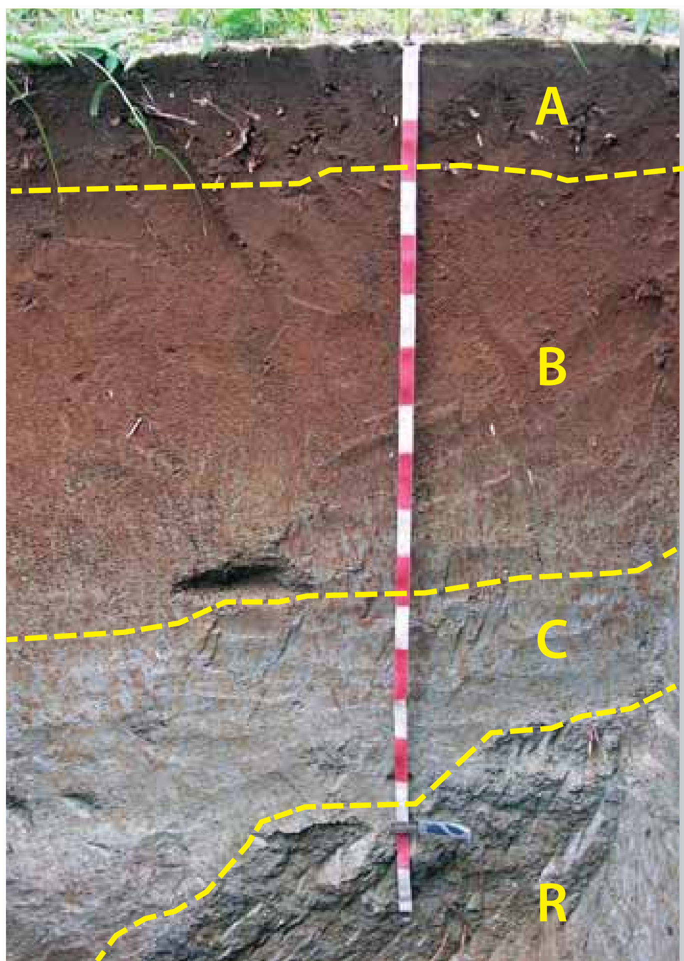
When a vertical section of the soil is examined, the uppermost thin layer normally contains the undecomposed or slightly decomposed remains of plants lying on the surface of the soil. This layer is called an organic horizon and is referred to by the letter 'O'. The O horizon is not saturated by water for prolonged periods and its mineral content is very low. Where the accumulations of organic material on the soil's surface are saturated by water for prolonged periods, this is referred to as an H horizon.

Organic matter in both the H and O horizons may be further divided into i) slightly decomposed - plant remains are visible to the naked eye; ii) an intermediate phase where decomposition is greater but plant remains are still visible; iii) completely decomposed organic layer on top of the mineral soil.

Beneath the O horizon, a dark horizon containing a mixture of organic and mineral material can be recognised which is referred to by the letter 'A'. The A horizon is the topsoil, which contains most of the organic material within the soil, hence its darker colour. It is the engine room of the soil where most of it's biological and chemical activities occur (e.g. biomass growth, dead litter and root decay and release of nutrients, formation of organic acids and their reactions with minerals, etc.). If the topsoil layer is removed by erosion or human activity, most of the soil's ecological potential goes with it. While the topsoil layer will regenerate over time, if left undisturbed, it may take hundreds of years for its full original potential to be restored.

Below the topsoil (O and A horizons) is the mineral subsoil containing one or more brighter coloured layers that are referred to by the letter 'B'. Apart from Podzols (see page 59), the B horizons contain much less organic material than topsoil (making them different in colour) but they are still exploited by plant roots and soil animals which use the water, air and nutrients stored in them. Brownish, yellow or reddish colours originate from iron oxides formed by weathering in the soil, whereas greyish tones result from chemical reaction in reducing conditions. Towards the base of the subsoil, the soil structure gradually becomes less apparent as the factors affecting its development decrease in influence.

Eventually, a layer is reached where the influence of soil-forming processes is less apparent. This layer is referred to by the letter 'C'. This horizon lies above hard bedrock or parent material. The characteristics are usually very different to the A and B horizons and may contain weathered blocks of the underlying geological substrate.



This photograph shows a classic A-B-C-R soil horizon sequence under arable cultivation in Tanzania.

The greyish, soft C horizon has weathered from the hard bedrock below (R), and provided the parent material for the development of the A and B horizons. The uppermost, dark A horizon (0 - 20 cm) indicates a higher level of organic matter. Below is a well structured, reddish B horizon (20 - 100 cm) with high amounts of iron oxides and clay, as a result of weathering and soil-forming processes.

Plant roots and burrows are clearly visible in both the A and B horizons. (EM/JRC/LJ)

The R horizon basically denotes the layer of hard bedrock underneath the soil. Soils formed in situ will exhibit strong similarities to this layer.

Where do the soils of Africa come from?

Soil-forming factors

As we can see from the pictures on this page, the appearance and characteristics of soils can vary considerably from place to place. The next few pages of the atlas will describe the main soil-forming factors and illustrate how they dictate the properties of a particular soil.

Vasily Vasil'evich Dokuchaev, commonly regarded as the father of pedology, was the first person to articulate that geographical variations in soil characteristics were related to climatic and topographic conditions as well as geological factors (parent material). His ideas were developed by a number of soil scientists, including Hans Jenny who, in 1941 [6], established a mathematical relationship that states that the observed properties of soil are the result of the interaction of many variables, the most important of which are:

Parent Material

Topography or position in the landscape

Climate

Living organisms, especially vegetation

Human activities

Time

Jenny expressed this relationship through a formula:

soil = f (climate, organisms, topography, parent material, time)

According to this formula, variations in parent material, climate or the age of the soil will result in specific soil characteristics.

For example, the weathering of solid bedrock through processes such as heating-cooling or freeze-thaw cycles (determined by topography and climate) produces a matrix of rock fragments (also known as regolith). Further, weathering leads to the production of finer structures containing crystalline minerals that have been liberated from the rock. These fine-texture materials provide the conditions for seeds to germinate and plants such as lichens and mosses to become established. The growth of vegetation is supported by the decomposition of minerals into simple molecules or compounds that act as plant nutrients. As plants become established, dead leaves will fall on the surface and decay to form thin organic layers, which in turn, support the next cycle of plant growth by returning the nutrients to the soil. Over time, the parent material becomes covered and buried by more and more organic matter allowing larger plants to grow. The slope or aspect of the site may determine growing conditions but also the drainage and inputs or removal of material. In this way, a soil will form with characteristics that reflect the interplay between the various factors.

A changing climate may reduce the weathering processes and thus halt the supply of parent material and the release of minerals. Alternatively, climate change may favour a more luxurious vegetation community, leading to the production of more plant matter, resulting in deeper organic layers. In both cases, the soil characteristics will be different from the initial example.

Many people argue that these basic soil-forming factors are not truly independent. Climate has an obvious bearing on living organisms while at the same time, the (micro)-climate at the surface of the soil may be very different to the general regional climate. This micro-climate may itself be controlled by topography which, in turn, is the result of the interaction between the underlying geology (in many cases the parent material) and the regional climate.

Nevertheless, the underlying principles of soil formation have been shown to be sound. An additional important factor that should not be ignored is the influence of human activities. Soil processes and characteristics can be significantly altered by the way that the land is used or managed. Drainage, the addition of fertilisers or the removal of natural vegetation are only a few examples of how soil characteristics can be changed artificially.

Much more information on soil forming processes can be found in most general soil text books such as [7, 7a].

The three photographs on this page illustrate the variety of soil characteristics, which in turn are driven by the interplay of soil-forming factors. This photograph from Tanzania shows a deep, coarse-textured, iron-rich soil that has developed under a tropical climate. The darker band just below the surface (0–20 cm) is the result of ploughing. (VL)

A fine-textured soil from Ethiopia with high levels of swelling and shrinking clay minerals under a crop of teff (*Eragrostis tef*). Initially derived from the weathering of basic rocks such as basalt, the clays were later redeposited in still water conditions. The dark colour indicates that iron is virtually absent in this soil. Note the cracks and smooth surfaces of sheer planes which are evidence of churning within the soil as a result of shrinking and swelling in wet and dry conditions. The churning has even pushed up a big piece of limestone bedrock. (KV)

A coarse-grained soil composed primarily of quartz particles deposited by the wind, This soil from Morocco has developed in a semi-arid climate. Strong winds have transported sand grains from the Sahara. In such soils, organic matter levels and water holding capacity are very low. Trees can grow in such soils because they can send roots to access groundwater deep below the surface. (EM)

Africa

Africa is the world's second-largest and second most populous continent, after Asia. Covering an area of around 30 million km², Africa covers 20% of the Earth's land surface area. With just over one billion people living in 55 countries, Africa accounts for about 14% of the human population.

Separated from Europe by the Mediterranean Sea, Africa is joined to Asia at its northeast extremity by the Isthmus of Suez. The Sinai Peninsula is generally regarded as Africa since it is actually part of the Great Rift Valley, the great fracture in the Earth's crust that begins in East Africa and runs up the Red Sea. The continent is bounded by the Indian Ocean to the east and the Atlantic Ocean to the west. Madagascar and various island groups such as the Azores, the Canaries, the Seychelles, Comoros and Cape Verde are also associated with the continent.

Map showing the main geographical elements of the African continent. (LJ)

The distance from the most northerly point of the continent, Ras ben Sakka in Tunisia (37°21'N), to the most southerly point, Cape Agulhas in South Africa (34°51'S), is approximately 8 000 km. While the journey from Cap-Vert in Senegal (17°29'W) to Ras Hafun in Somalia, (51°27'E) is approximately 6 900 km. Taking the Cape Verde Islands as the western-most expression of the continent would add a further 560 km. Due to its generally smooth shape, the coastline of Africa is estimated to be around 28 000 km long, compared to 32 000 km for Europe, which covers only about a third of the surface of Africa.

The highest mountain is Kilimanjaro on the Kenyan-Tanzanian border with an elevation of 5 895 m while the lowest point is Lake Assal in Djibouti at 156 m below sea level. The average elevation of the continent is around 600 m but many regions are significantly higher (e.g. Ethiopia, Morocco, South Africa).

Of the fifty-four sovereign states that make up Africa, Algeria is the largest country. The smallest (and with the lowest elevation) is the Seychelles. The smallest nation on the continental mainland is The Gambia.

Readers are encouraged to view the UNEP Africa Atlas [20] which provides some striking views of the African environment.

Africa – the name!

There is no outright certainty in the origin of the word Africa; but three theories are commonly proposed:

- *Afri*, the Latinised version of the Phoenician word afar meaning dust was used by the Romans to describe Carthaginian territory around modern Tunisia. The suffix *–ca* in Latin denotes a country. The term was gradually extended to the whole continent.
- In ancient Greek, the prefix *a-* indicates an opposite; hence, the phrase *phrike* (φρίκη), meaning "cold and horror", becomes "without cold and horror" implying a warm and inviting land.
- The Egyptian word "*af-rui-ka*" literally means "to turn towards the opening of the mother's womb" and recognises Africa as the birthplace of their earliest ancestor

Africa is the most multilingual continent in the world. UNESCO has estimated that around two thousand languages are spoken. The four major indigenous language families are Afro-Asiatic, Nilo-Saharan, Niger–Congo and the Khoisan.

Soil-forming factor 1: Parent material

Parent material refers to material from which the soil has been derived and, in most cases, is of geological origin (see peat on page 30). The nature of the parent material can have a profound influence on the characteristics of the soil. For example, the texture of sandy soils is determined largely by the parent materials, which in turn controls the movement of water through the soil. The mineralogy of the parent material is mirrored in the soil and can determine the weathering process and control the natural vegetation composition. For example, lime-rich soils are generally derived from calcareous rocks (e.g. limestone, chalk) or sediments derived from such deposits. In turn, lime-rich soils can offset the development of acidic conditions but may not support plants that are not tolerant of alkaline soil conditions (e.g. rhododendrons).

Two types of parent material are recognised: a) unconsolidated deposits or loose sediments that have been transported by ice, water, wind or gravity and b) weathered materials directly overlying the consolidated hard rock from which they originate. In both cases, the parent material can be weathered through physical destruction of rock (freezing or drying cycles) or chemical reactions (dissolution of elements). Weathered parent material is often referred to as saprolite.

While the forces created by the expansion and contraction of minerals, induced by daily temperature variations, cause rocks to shatter and exfoliate (especially in hot deserts), in most cases water is the dominant agent in weathering processes. Water can cause rocks to shatter through repeated freezing and thawing of water trapped in rock cavities. Water also initiates solution and hydrolysis (the destruction of a compound through a reaction with water that produces an acid and a base) that liberate minerals contained within the rock. Water also supports life which, in certain situations, is a major contributor to the weathering process. Plant roots can cause physical weathering as they grow and expand inside cracks in the rocks. Roots and decaying vegetation also produce organic compounds such as solvents, acids and alkalines that enhance the actions of percolating rainwater.

The degree of weathering depends on a number of environmental factors such as temperature (determined by climate, exposure and altitude), the rate of water percolation (determined by texture, relief, climate), the presence of oxygen (again texture and climate), the surface area of the parent material (largely determined by the geological structure) and the mineralogy of the parent material (for example, quartz is much more stable than olivine).

Weathering continues in the soil following a sequence from the least to the most stable minerals. For example,

- Early weathering: clay fraction of young soils, often characterising dry conditions

    Gypsum, Calcite, Hornblende, Biotite

- Intermediate weathering: temperate soils, often with natural grass or forest vegetation

    Quartz, Muscovite, Vermiculite, Montmorillonite

- Advanced weathering: clay fraction of highly weathered soils of humid/tropical regions

    Kaolinite, Gibbsite, Hematite, Goethite

Minerals undergo changes that cause the formation of secondary minerals and other compounds that are soluble in water (to varying degrees).

The distinctive features for Africa from a geological point of view are four-fold:

- most of Africa is made up of very old rock, often exposed to the surface. In most cases it is crystalline and derived from igneous sources (i.e. magma) and has often been altered chemically (metamorphised);
- the continent is slowly being torn in two along the great East African Rift Valley - volcanic activity is common;
- large parts of the African land surface have been geologically stable for millions of years which gives rise to deep weathering profiles;
- large parts of Africa are covered by recent sediments, in particular, wind blown sand.

A thorough summary of the geology of Africa is given in [8].

Examples of soil formations on continuous, hard bedrock in Tunisia **(left; GT)** and transported sediments in East Africa **(right; EM)**, in this case, of fluvial origin. Where consolidated parent material lies close to the surface, soil depth is generally shallow and horizon development is weak. Unconsolidated sediments can completely mask the characteristics of the underlying bedrock.

Rock types

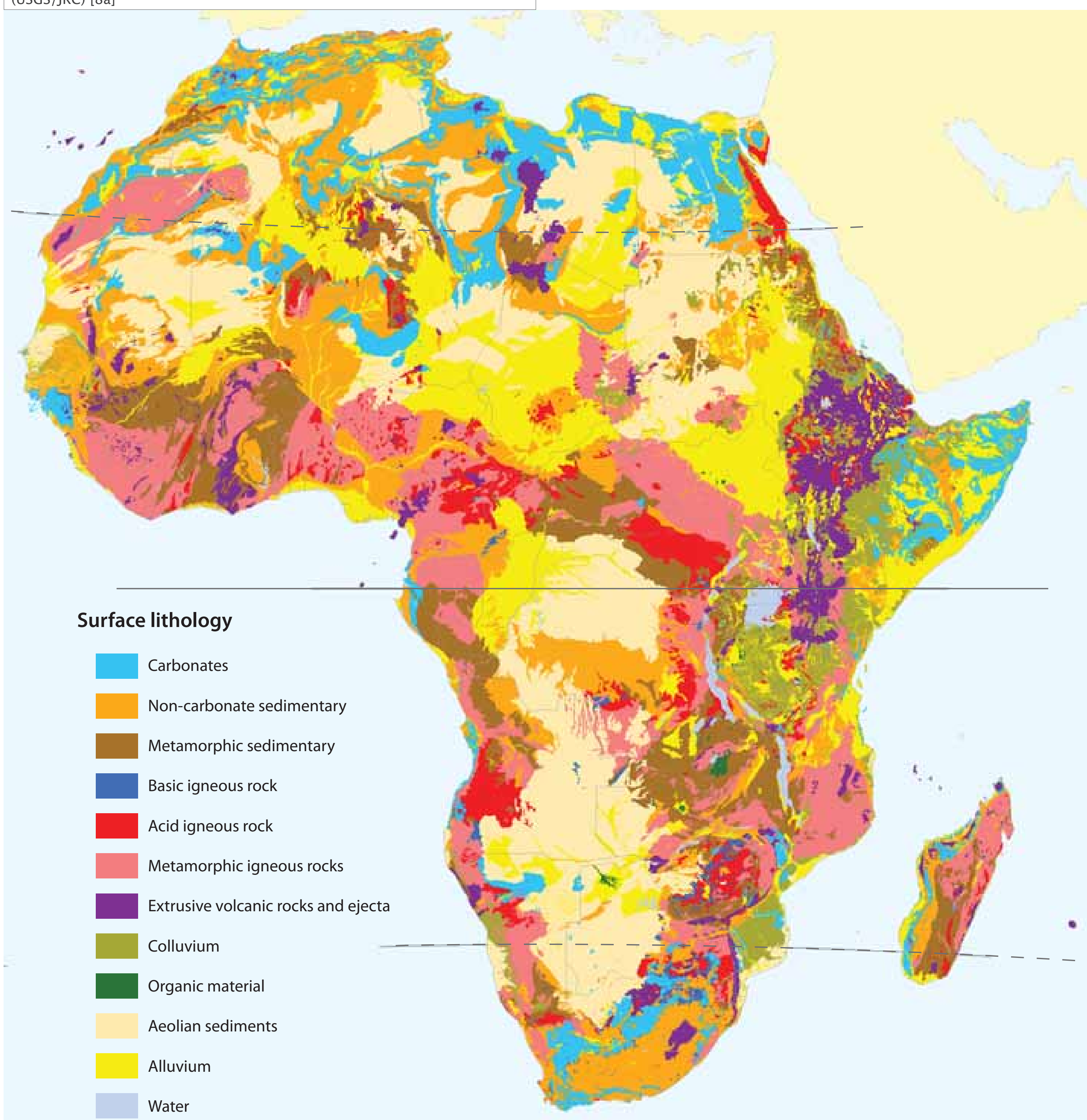
Igneous rocks are formed by the solidification of molten magma and are the original source of all other rocks. They include rocks such as granite, dolerite and basalt and are generally divided according to the presence of the mineral quartz.

Sedimentary rocks are formed by the deposition of weathered material by wind or water. Shales are deposited on ocean floors. Conglomerates and sandstones are composed of resistant fragments of other rocks while limestones and chalk are created through the precipitation of calcium carbonate from solution.

Metamorphic rocks are igneous or sedimentary rocks that have been transformed by intense heat or pressure resulting in changes in mineralogy and structure. Examples include gneiss, marble and slate.

The map below shows the lithological properties of the surface geology of Africa. Lithology describes the mineral composition and structure of geological material which is based on rock formation (i.e. whether it is igneous, sedimentary, metamorphic) and mineralogy (e.g. carbonate, silicic, mafic). This map is a good proxy for soil parent material as it only reflects surface conditions and not the underlying bedrock. It should be noted that the general nature of this map means that at a local level, the conditions may be quite different to that shown.

Other than the terms alluvium (deposited by water), aeolian (deposited by wind), organic (peat deposits) and colluvium (transported by gravity), all of which denote recent deposition, the age of material is not indicated. The preponderance of wind-blown sediments across Africa is striking as are the volcanic areas. Please consult the glossary at the end of the atlas, the adjacent text box and page 28 for an explanation of the geological terms. (USGS/JRC) [8a]



Soil-forming factor 2: Topography

The shape of the land surface, also referred to as relief or topography, is a key soil-forming factor as it has an important influence on local climate, vegetation and the movement of water. Mountains can affect the amount and intensity of precipitation and vegetation growth while locally, the angle or slope of the ground controls drainage and movement of material. Even small variations in elevation can be important in flat lands. River terraces or small depressions can lead to localised improved drainage or waterlogging respectively. Micro-topography can be particularly important if saline groundwater occurs close to the surface as it will affect evaporation rates.

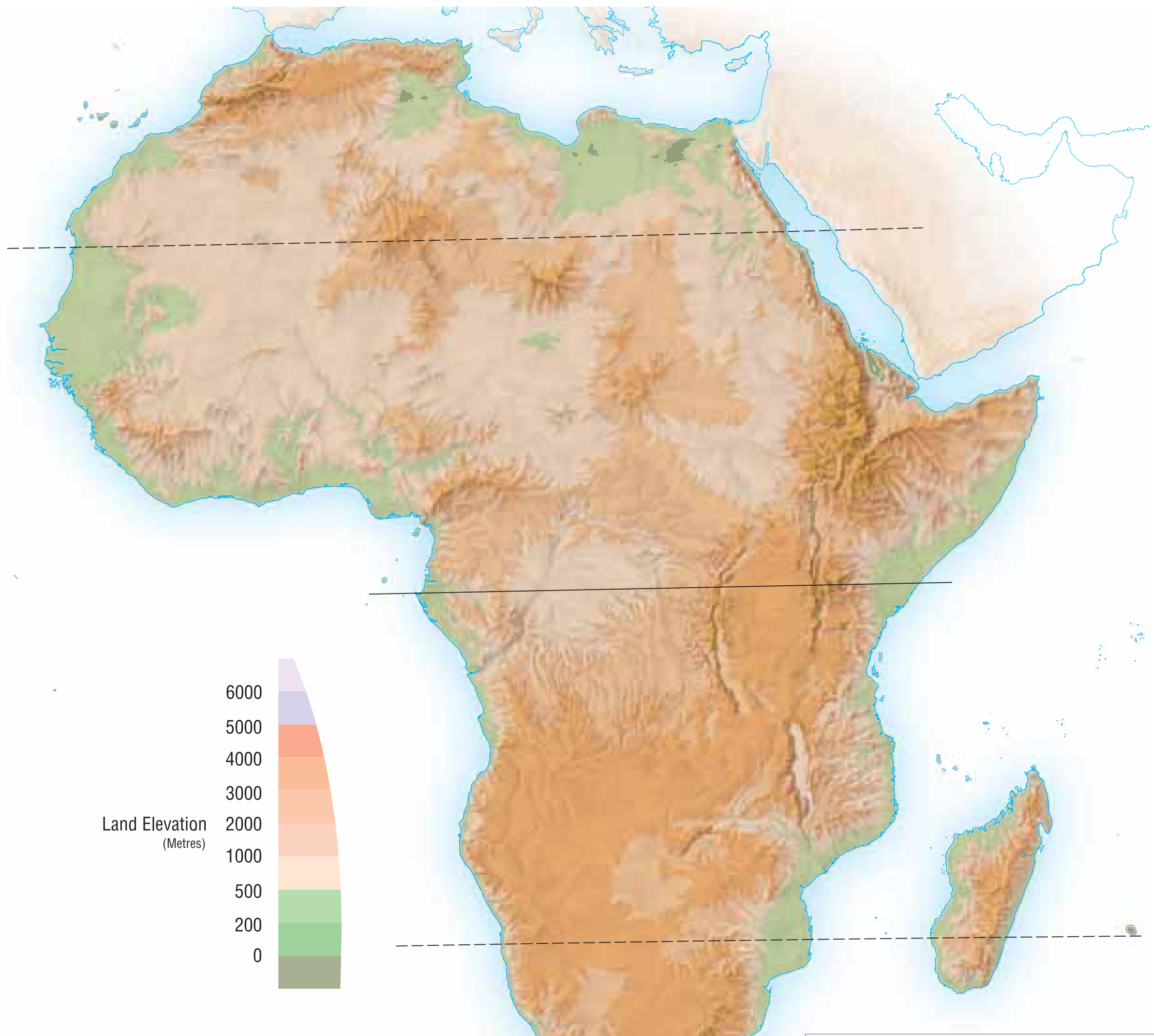
The position in the landscape is very important. Generally, soils found at the top of a slope tend to be freely draining while those at the foot of a slope or in the valley bottom are often poorly drained (see page 40). In some cases, the water table may be near or at the surface. In this situation, different soils may form on the same parent material, climate and even vegetation type (e.g. a grass-covered slope). Soils occurring on the middle of slopes receive sediment and solutions from higher up but at the same time lose material to soils below. In these cases, the actual shape of the slope is important as smooth, irregular, convex or concave slopes will result in different soil characteristics.

The map on the **right** shows the variation in elevation of the land surface of Africa in metres above sea-level. The map is based on measurements made by a specially modified radar sensor carried onboard the Space Shuttle as it orbited the planet. (WorldClim [9])

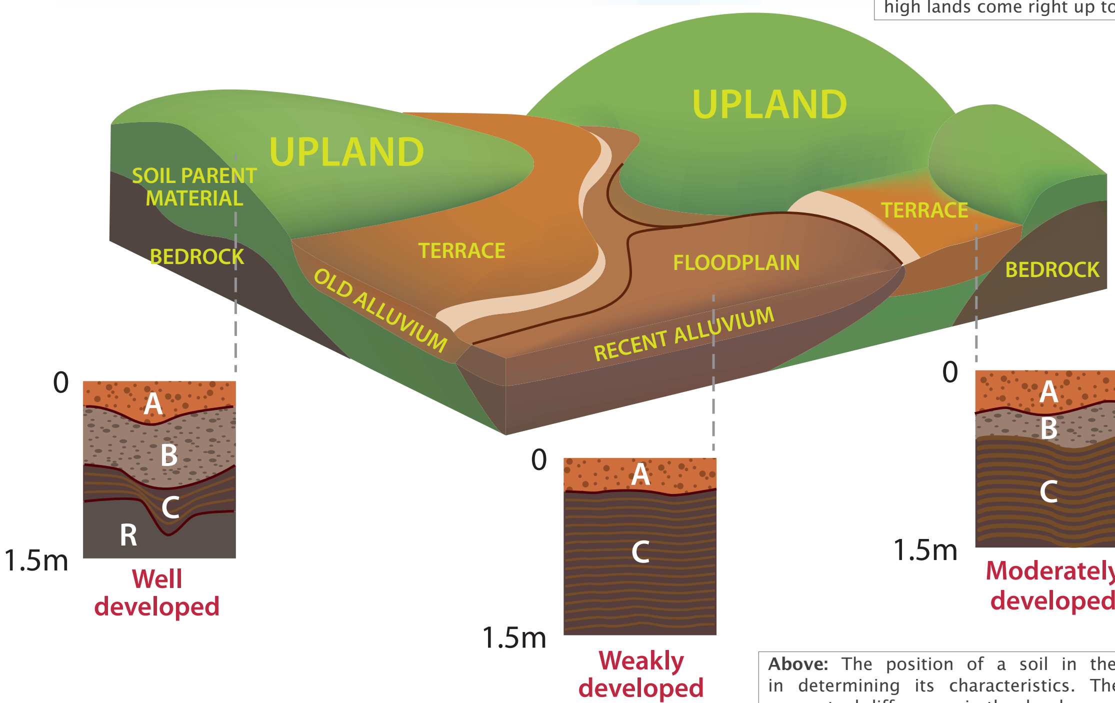
The turquoise and dark green colours represent areas below or just above sea-level respectively: the low-lying salt lakes of North Africa are particularly evident. The light green areas show the extent of low relief landscapes such as plains which are generally flat or only gently undulating. Light pink denotes the high plains where the landscape begins to show evidence of soil erosion on steeper slopes. The orange colours signify upland regions which in some places give way to mountains (dark brown). The highest elevations in the region (light blue) are found in East Africa where Kilimanjaro reaches a height of 5 895 metres above sea-level, closely followed by Mount Kenya (5 184 m), the Ruwenzori Range (5 060 m) and the Ras Dashen mountains of Ethiopia (4 550 m). The average elevation of the African continent is approximately 600 m above sea level. In contrast with other continents, Africa is characterised by a comparatively small area of either very high or very low ground. It is interesting to note that only 6% of Africa has an elevation of below 100 m. Moderately elevated tablelands are the characteristic landscape, broken by higher peaks and ridges.

As a general rule, the higher tablelands lie to the east and south, while a progressive diminution in altitude can be observed towards the west and north. The Atlas Mountain Range is unconnected with and separated from the south by a depressed basin. The high grounds of Hoggar and Tibesti are constituted of volcanic material standing on broad uplifted areas. The third area of high elevation is formed by the Ethiopian Highlands, a rugged mass of mountains forming the largest continuous area of altitude in the whole continent where hardly any of its surface drops below 1 500 m. The region is often called the 'roof of Africa'.

The lowest points on the African continent are Lake Assal in Djibouti, which is 156 m below sea level, and the Danakil Depression in Ethiopia, which is 125 m below sea level.

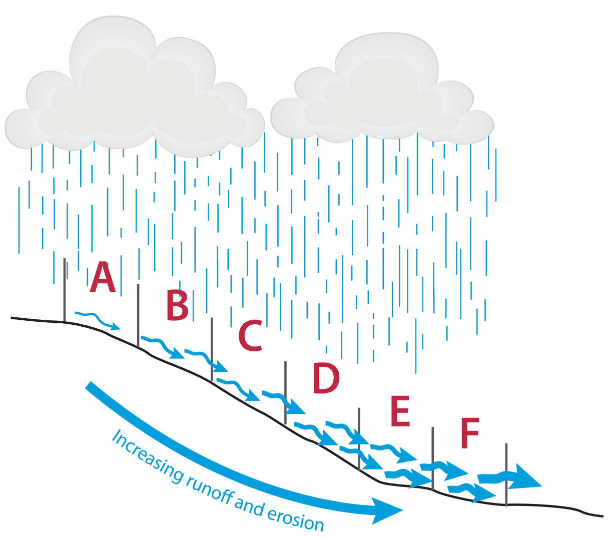


Map showing the elevation of land in Africa. The darker brown colours denote areas of higher elevation while the green areas are below 500 m. The map clearly shows that than most of the continent is above 500 m, with large tracts of land above 1000 m. In many places, the high lands come right up to the coast. (LJ)



Above: The position of a soil in the landscape is important in determining its characteristics. The graphic illustrates the conceptual differences in the development of soil profile according to a specific topographic setting (UM/TC).

Below: Soils occurring at the foot of slopes receive greater amounts of water and sediment compared to those on higher ground. While erosion is considered a threat to soil functions, it can also be regarded as a soil-forming process by depositing new parent material at the foot of slopes. However, soil at location A will probably be well drained while at location F, waterlogging or saturated ground may be common. (JRC/LJ)



The Catena

From the Latin for chain, the catena is a term that describes the sequence of soils occurring on slopes, where the parent material is common. In this case, the influence of relief dominates other soil forming factors. The theory of the catena originates from a soil reconnaissance survey that was carried out by an agricultural officer, Geoffrey Milne, in what is now Tanzania during 1935-36. The catena concept reflected the understanding of landscape that these early surveyors brought to field work in Africa. Additionally, they utilised the local farmers who had an indigenous but sophisticated understanding of the role of topography in determining soil types.

Milne became a one of the outstanding figures in international soil science. His concept of the soil catena linking soil development to topography provided the foundation for soil surveying. Milne's initial ideas were set out in a paper published in 1947 [10]. His early records, the basis for his subsequent mapping of soils in the savannah landscape, are kept in the WOSSAC archive (see page 139).

The photograph shows a very weathered granite outcrop in Sukumaland, Tanzania. In fact, this is the upper section of the original catena described by Geoffrey Milne in 1936 (see box left). The pronounced horizontal crack in the rock is a pressure release surface (also known as a desquamation slab). The soil at the base of the catena is a Petric Plinthosol – characterised by an accumulation of iron that hardens irreversibly when exposed to air and sunlight (see page 26 for corresponding photograph). (JD)

Soil-forming factor 3: Climate

Climatic zones

Soil formation depends enormously on the climate as temperature and moisture levels affect weathering processes and biological activity. Where precipitation exceeds evapotranspiration, leaching or saturated soils can occur. When the opposite is true, salts can rise to the surface. Chemical weathering will be very active in areas with high temperatures and high humidity while physical weathering will dominate in hot, dry desert regions.

With the Equator running through its centre, Africa has the largest tropical area of any continent and about 75% of the land area lies within the tropics. In countries south of the Equator the seasons are the opposite to the countries that lie north of the Equator. The broad climatic pattern of Africa is driven by its position around the Equator, the impact of cool ocean currents and the absence of mountain chains serving as climatic barriers. Seven main climatic zones can be distinguished:

- Hot, humid zone around the Equator where annual rainfall exceeds 1 500 mm - covering 14% of Africa;
- To the north and the south is a sub-humid savannah zone with annual rainfall between 600 mm and 1 200 mm, covering 31% of the land area. Rainfall becomes increasingly seasonal further from the Equator;
- Semi-arid steppe zone with an average rainfall equaling or less than 600 mm which falls only in the summer months, covering 8% of the total land area;
- Dry desert zone occupying nearly half of the African land area (47%). Annual rainfall is erratic, less than 100 mm – in some areas this is zero. Daily and seasonal extremes of temperatures are large with the average summer temperature greater than 35°C;
- Mediterranean climate in the extreme north and south with high temperatures in the summer and warm autumn and winter months with rainfall;
- The highlands of eastern Africa, particularly in Kenya and Uganda, where rainfall is well distributed throughout the year and temperatures are constant throughout the year;
- The high plateau of southern Africa which has a temperate climate;
- On a few high mountain summits, a cool temperate climate can be found, even on the Equator!

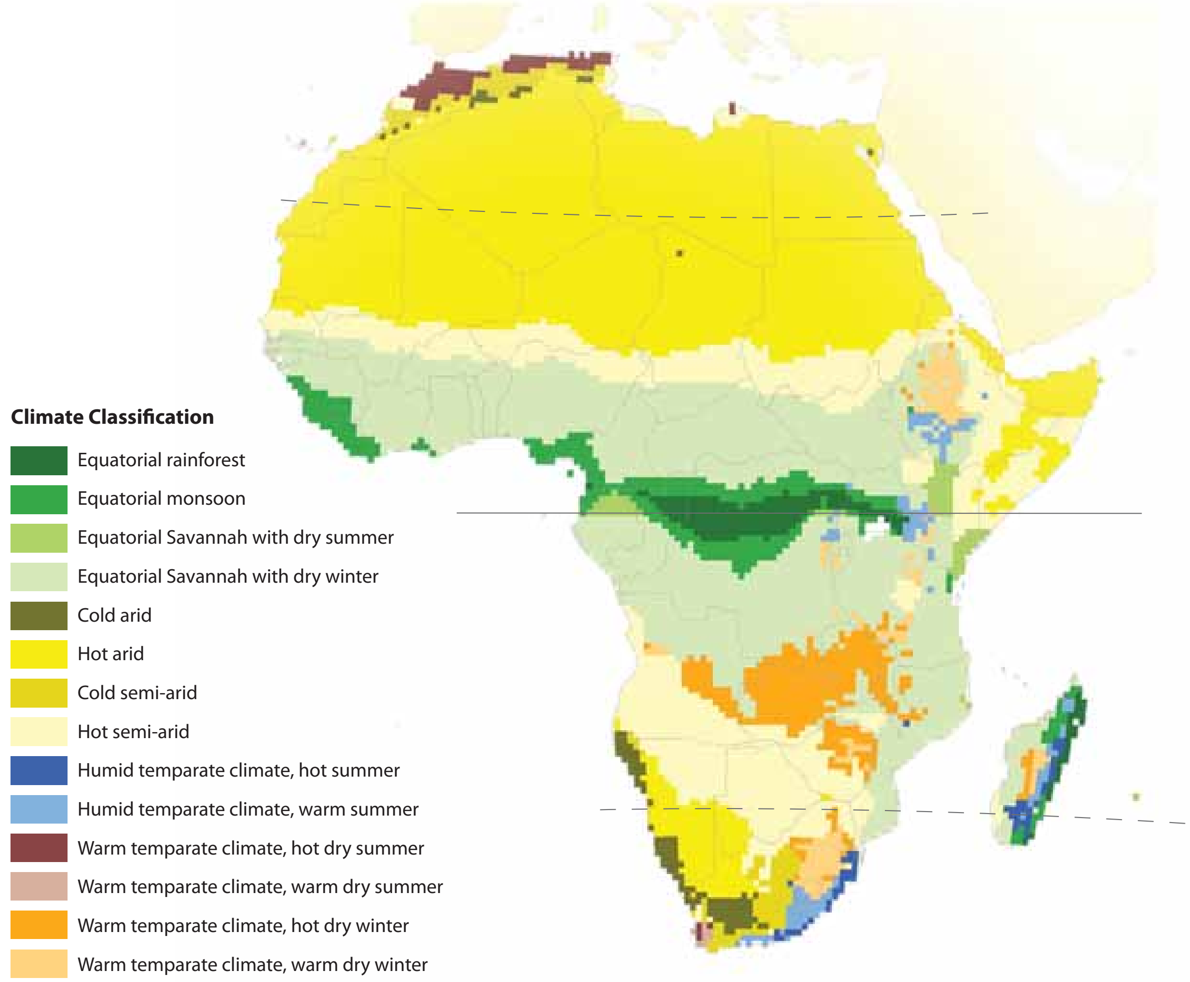
Annual temperature range

Temperature and fluctuations in temperature have important bearings on soil-forming processes. The map on the right shows the annual temperature amplitude for Africa based on the difference between the mean temperature of the warmest and coldest months. This change depends on the annual cycle of incoming solar radiation, which in turn depends on the latitude and altitude, and the proximity of the ocean. Clearly, the continent of Africa exhibits tremendous variations in annual temperature ranges. The map shows nearly mirror patterns of zones either side of the Equator. The differences in the extent of the patterns is controlled by the shape of the continent: broad in the north while tapering to a point in the south. The region with the least variation is the equatorial zone. While a significant area displays a modest fluctuation of between 11 – 18°C, the range for the coastal fringe of the Gulf of Guinea and eastern DR Congo is only around 5 – 8°C. Away from the Equator, the more temperate climate of the savannah regions, the Sahel, the Maghreb and large parts of southern African are clearly evident. What may surprise many people is that the main desert regions display high temperature ranges, with parts of the Sahara registering variations in excess of 40°C. This is caused by a set of constant high-pressure cells over the tropic of Cancer which give rise to cool winters (c. 13°C) and hot summers (> 45°C). Snowfall in winter is commonplace in parts of the High Atlas Mountains of Morocco.

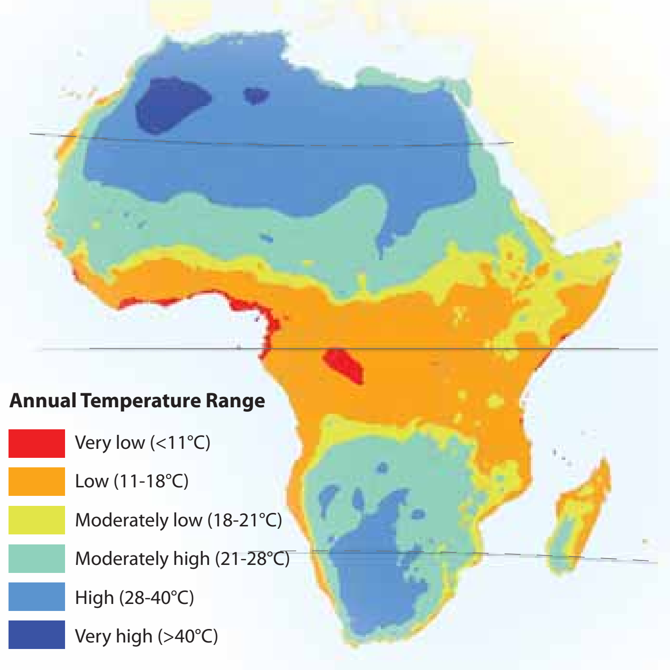
The Tropics

The tropics denote the area on the Earth where the sun is directly overhead at least once during the solar year. It is limited by the Tropic of Cancer, at approximately 23° 26' 16"N, and by the Tropic of Capricorn at 23° 26' 16"S, which marks the points where the Sun is directly overhead at the summer solstice (June 21 and December 21 respectively).

The term "tropical" is sometimes used in a general sense to denote a climate that is generally warm andmoist all year-round and where there is often with a lush vegetation. However, in a strict sense, a tropical climate is not arid and all months have an average temperature > 18°C.



Map of the major climatic zones of Africa according to the updated Köppen-Geiger classification scheme. Most of Africa has a warm or hot climate, but the humidity and amount of rainfall varies dramatically from area to area. Eight per cent of Africa has a tropical climate with 10-12 months of rainfall. The remaining area experiences climatic contrasts with either not enough water when needed or an excess of water which cannot be used. Half of the continent has inadequate precipitation. Within these zones, altitude and other localised variables produce distinctive regional climates. Regionally, the climate varies cyclically over periods of decades or centuries. Climate change, especially indicated by prolonged drought is one of the most serious hazards affecting the agricultural sector of the continent since most of the crops are rain fed. As has been shown several times in the past 100 years, adverse changes in climate can have a devastating effect on the livelihood of people. (JRC) [11]



Map showing the annual temperature amplitude or range for Africa based on the difference between the monthly mean temperature of the warmest and coldest months. (WorldClim/ JRC) [12, 12a]

Intertropical Convergence Zone

One of the main drivers of climate in Africa is a feature known as the Intertropical Convergence Zone (ITCZ). Winds originating from high pressure cells in the northern and southern hemispheres come together over the Equator, where they are heated by the sun and driven upward. This rising movement cools the air, forcing the moisture out, which falls as precipitation. The dry air cycles back toward the subtropics where it descends, producing arid climates at approximately 20 degrees north and south of the Equator. In Africa, the ITCZ is located just south of the Sahel at about 10°N. Around July, the ITCZ moves northwards bringing rain to the Sahel. From December to January, when the sun has moved to its southern limit, the situation is reversed, the convergence zone moves southward and rain falls over parts of Southern Africa. Seasonal variation in this position can result in drought conditions.

Variations in this cycle can result in drought conditions.

The variety of climatic zones in Africa gives rise to a tremendous diversity of landscapes. **Above:** A Saharan sand sea in Libya - while dune fields are not that common, large parts of Africa have a desert or semi-arid climate where annual precipitation is less than 250 mm and is often, much lower. Vegetation is very low or non-existent. Soil-forming processes are limited. (BN)

Below: Tropical forest along the Sanaga River in southern Cameroon. Here water is plentiful and vegetation can flourish. The slow and winding river carries lots of sediment which serves as parent material for soil. The soils of this part of Cameroon are very different to those of the Libyan desert. (RJ)

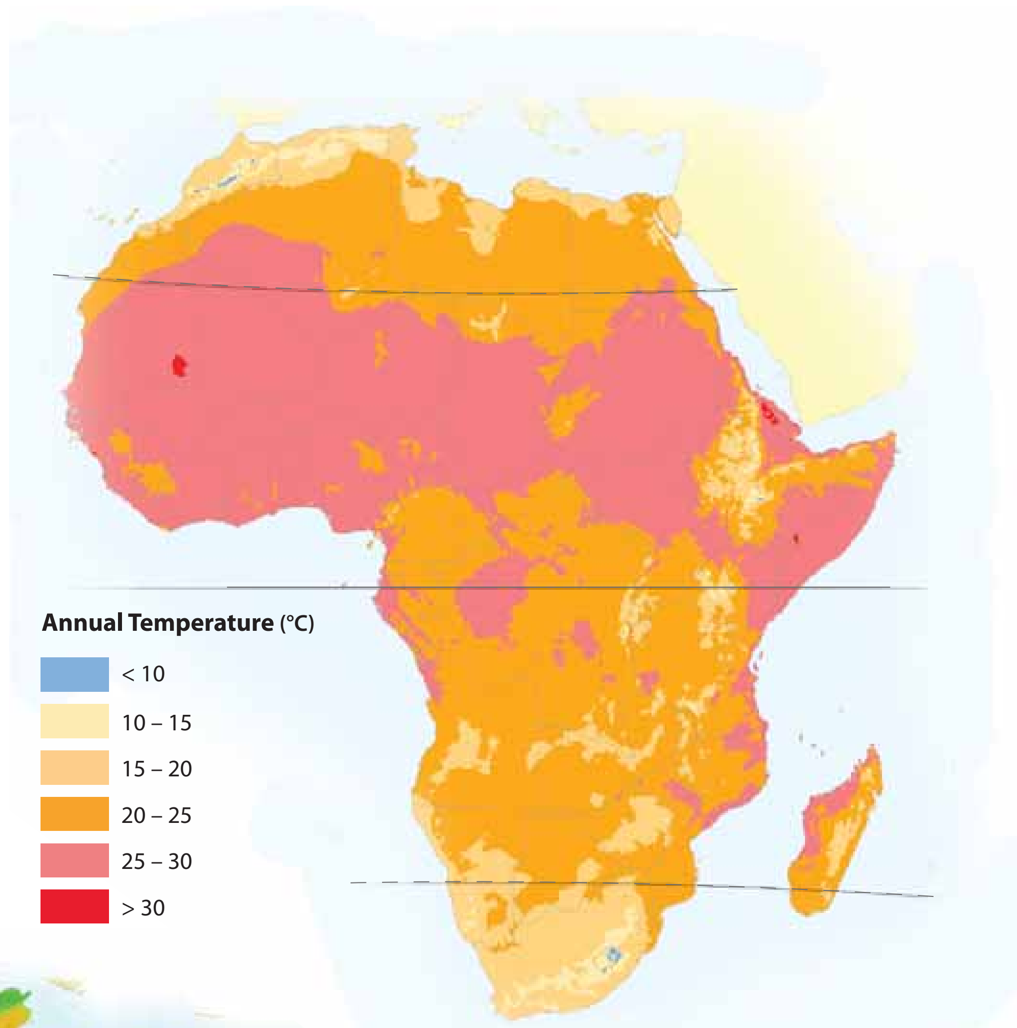
Temperature

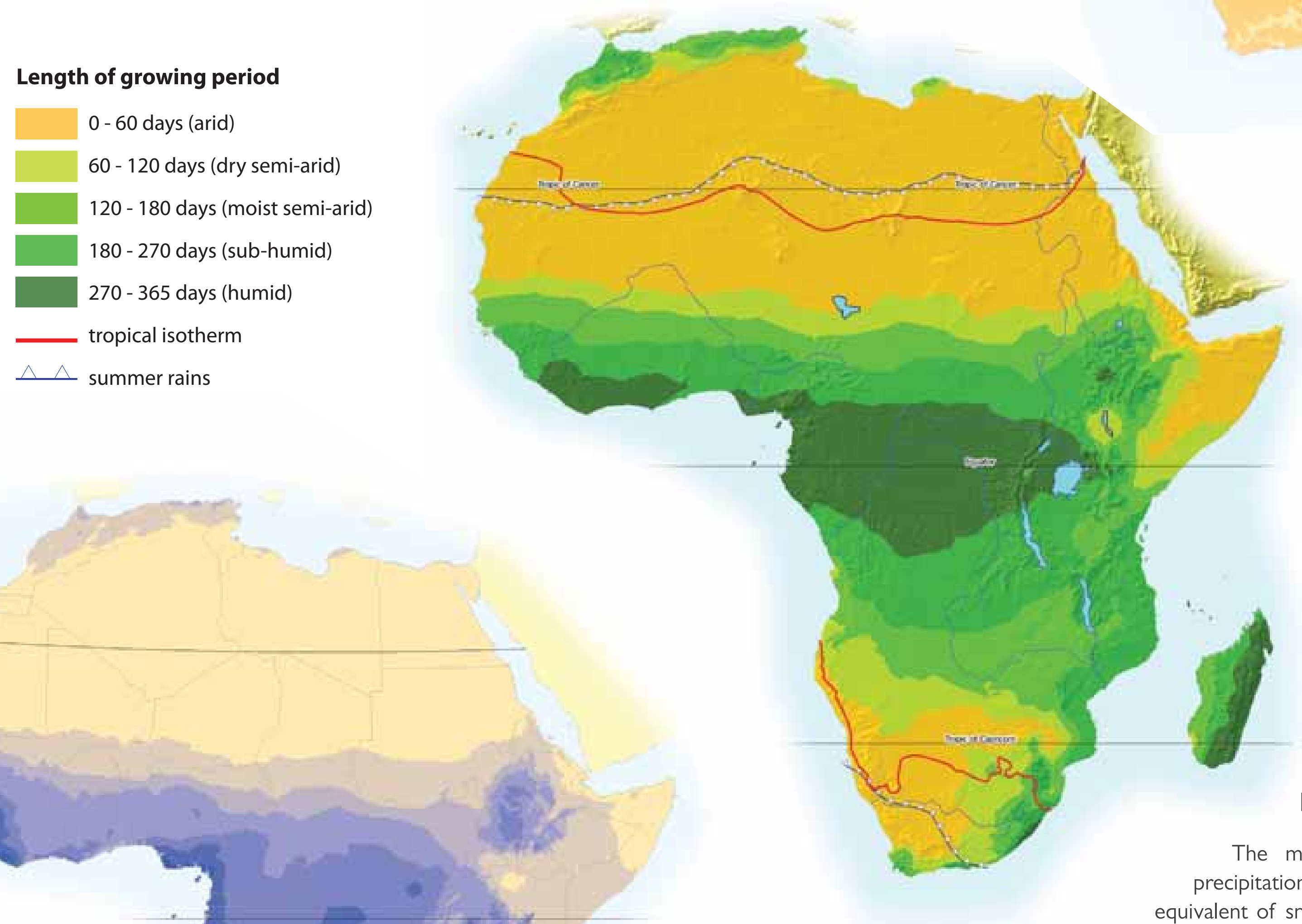
The map shows the patterns of mean annual air temperature for the African continent. Africa's highest temperatures (dark red colour) occur in Mauritania, Ethiopia and Somalia. The highest temperature ever recorded in the world was 58°C in the shade at Al Aziziyah, Libya, on September 13, 1922. At I-n-Salah, Algeria, and along the Red Sea coast, July temperatures often reach 46°C or higher almost every day. In fact, the daily temperatures in the Danakil Depression of Ethiopia and the Eritrean lowlands are consistently more than 40°C and can regularly soar to 50°C. During the night, temperatures may drop sharply. The Sahara also has the greatest seasonal range of temperatures in Africa. Winter temperatures in the Sahara average from 10°C to 16°C.

To many people's surprise, temperatures near the Equator are not excessively high with average daily temperatures being a constant 24 - 27°C throughout the year. Extensive cloud cover and heavy rainfall prevent temperatures from rising much over 33°C. The diurnal temperature change (i.e. between day and night) is usually between 2°C and 5°C which is greater than the annual temperature range of 2°C.

The coolest regions in Africa (blue colour) are in the northwest of Morocco (the Atlas Mountains) and eastern South Africa. The coldest place in South Africa is Sutherland in the Western Roggeveld Mountains where midwinter temperatures can reach as low as −15°C. Frost and snowfall are common on the high mountains of Africa. Glaciers can be found on Mount Kilimanjaro, Mount Kenya and the Ruwenzori mountains.

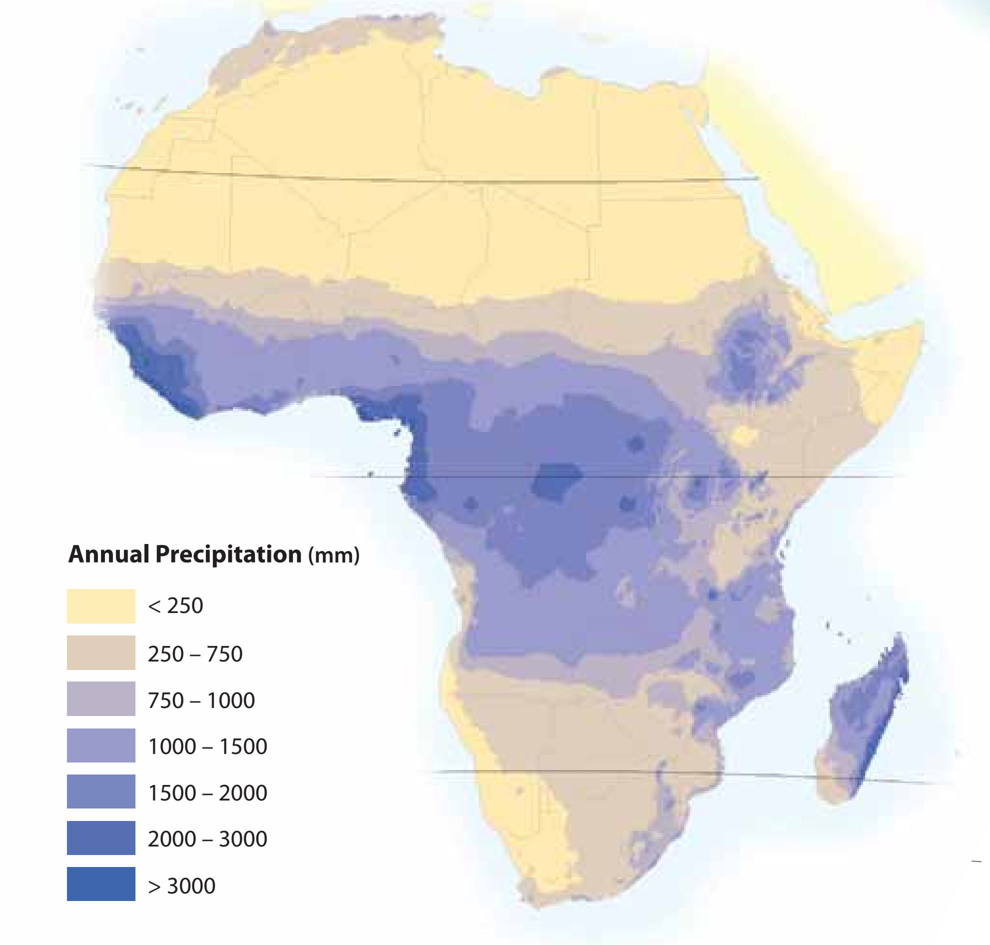
Above: Map showing the pattern of mean annual temperatures for Africa. Most of the continent has a mean temperature of above 20°C while some areas are much hotter. (WorldClim/JRC) [12, 12a]
Middle: Agro-ecological zones map of Africa based on the Length of Growing Period (LGP) and showing the climatic limits of the tropics. (GAEZ/SDD) [55b]
Below: Map showing the pattern of mean annual precipitation for Africa. Large parts of the continent have a mean annual rainfall of less than 750 mm (see correspondence with temperature map above). However, some parts of west and central Africa receive more than 5 m of precipitation every year and are among the wettest places in the world. (WorldClim/JRC) [12, 12a]





Length of growing period in the tropics

The Length of Growing Period (LGP) is the duration in days where rainfall is higher than half the reference evapotranspiration plus a period which is required for evaporating 100 mm of water that is presumed to be stored in the soil. The tropics are those areas with average monthly temperature in all months, corrected at sea level, of more than 18°C. Regions to the north and south of the tropics are known as the sub-tropics and have one or more months with temperatures between 5°C and 18°C. Areas with summer rains receive rainfall during the hottest time of the year. In the extreme north and south of Africa most rains fall during the coldest months of the year and are therefore called winter rainfall areas.



Rainfall

The map shows the pattern of mean annual precipitation (millimetres of rainfall and the water equivalent of snowfall). Rainfall is distributed very unevenly in Africa. Many areas receive either too much rain or too little. In parts of the west coast, for example, annual rainfall averages more than 3 000 mm. In the city of Monrovia, Liberia, more than 1 000 mm of rain falls on average during the month of June alone. In contrast, more than half of Africa receives less than 500 mm of rainfall yearly. The Sahara and the Namib Desert usually receive less than 250 mm a year and in some parts rain may not have fallen for six or seven consecutive years. The wettest place in Africa is Debundcha, in Cameroon. Situated on the south-western base of Mount Cameroon and facing the Gulf of Guinea, it receives a staggering annual average rainfall of 11 000 mm. In the forests of the Congo Basin and the coastal regions of western Africa, rain falls throughout the year. In the tropical rainforest climate, all twelve months have an average precipitation of at least 60 mm. The rest of Africa has one or two seasons of heavy rainfall separated by dry periods. In some regions of Africa, the amount of rainfall varies sharply from year to year rather than from season to season.

In relation to soil formation, humid conditions lead to more chemical weathering, higher levels of organic matter and leaching of minerals and organic matter. Heavy or prolonged rain can lead to soil erosion and saturated soils. A lack of rain will give rise to the development of crusts and accumulation of salts. Africa's climate has made agricultural improvement difficult. Rainfall records show that Africa's average annual rainfall has decreased since 1968 leading to prolonged and widespread droughts, especially in 1973, 1984 (when almost all African countries were affected) and 1992 (mostly restricted to Southern Africa). These failures have caused much suffering in which millions of people have died of starvation and related causes.

Weathering and climate

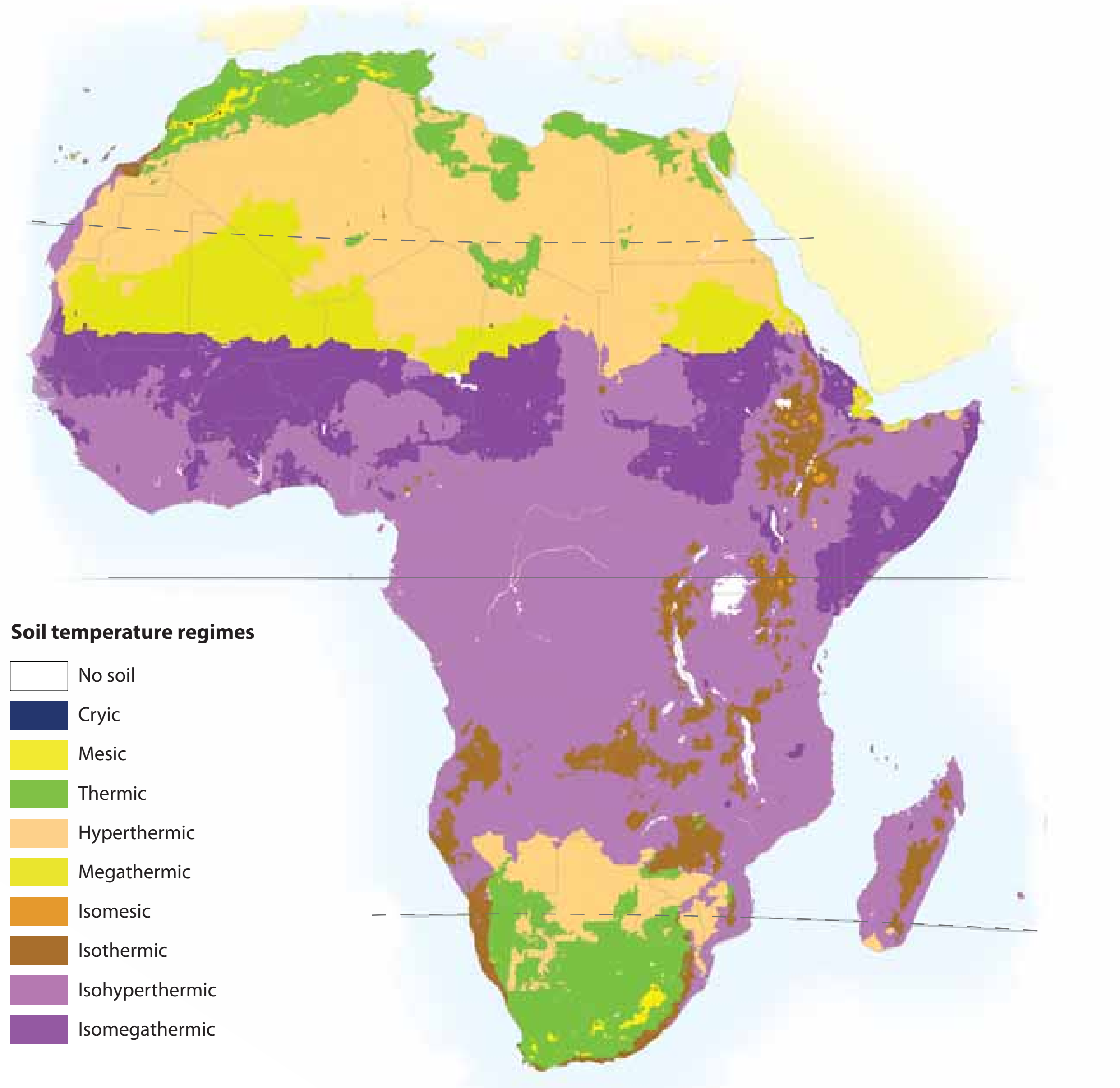
Studies have shown that tropical weathering rates, where temperature and moisture are at their maximum, are three and a half times higher than the rates found in temperate environments.

Soil temperature regimes

Soil temperature is an important attribute and key environmental factor in determining soil-forming processes, the natural distribution of plants and controls biological processes in the soil. Soil temperatures above or below critical limits severely inhibit seed germination, even if there is adequate soil moisture. The life cycles of many soil-borne pests and diseases are controlled by soil temperature. Soil temperature at a depth of 50 cm lags behind air temperature, commonly by one or two months. The length of lag depends on climate, shade, aspect, the thickness of organic layer and the thermal conductivity and heat capacity of the soil (governed by factors such as mineralogy and porosity).

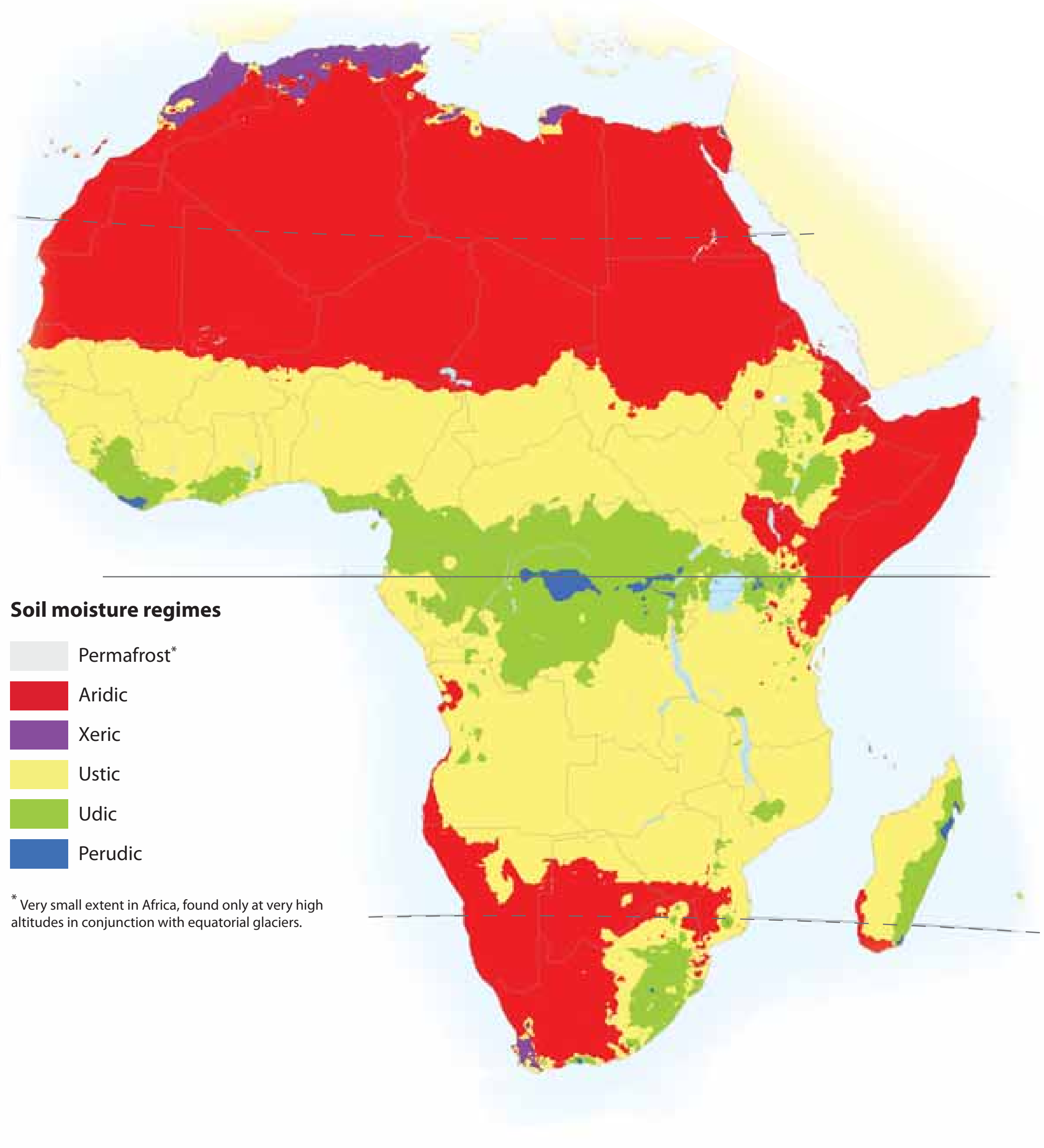
The map on the right shows the main soil temperature regions of Africa.

- Cryic: Very cold soils (mean annual temperature < 8°C but no permafrost) – very small extent in Africa, found only at very high altitudes in conjunction with equatorial glaciers.
- Mesic: Mean annual soil temperature (MAST) is 8°C or higher but lower than 15°C, difference between mean summer and winter soil temperatures ≥ 5°C.
- Thermic: MAST ≥ 15°C but lower than 22°C, difference between mean summer and winter soil temperatures ≥ 5°C.
- Hyperthermic: MAST ≥ 22°C and difference between mean summer and winter soil temperatures ≥ 5°C.
- Megathermic: MAST ≥ 28°C.
- Isomesic: MAST ≥ 8°C but lower than 15°C, difference between mean summer and winter soil temperatures ≤ 5°C.
- Isothermic : MAST ≥ 15°C but lower than 22°C,difference between mean summer and winter soil temperatures ≤ 5°C.
- Isohyperthermic: MAST ≥ 22°C, difference between mean summer and winter soil temperatures ≤ 5°C.
- Isomegathermic : Difference between the mean summer and mean winter soil temperatures ≤ 5°C.



Above: Map showing the pattern of soil temperature regimes for Africa, an important factor in determining soil-forming processes and biological processes operating in the soil. (USDA/JRC) [13, 13a]

Below: Map showing the pattern of soil moisture regimes for Africa. While the permafrost class may not be visible at this scale, permanent snow and ice exist on the summit of Africa's highest mountains. (USDA/JRC) [13, 13b]



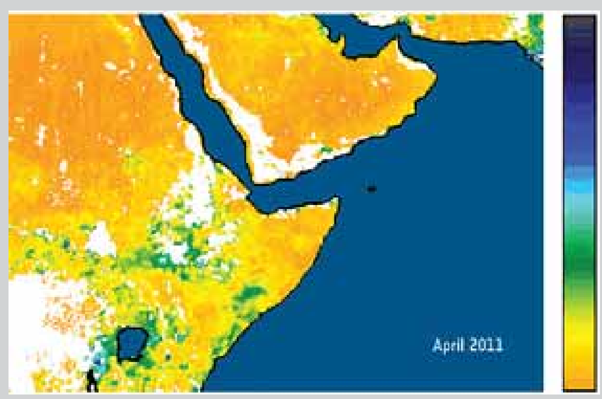
Soil moisture regimes

Soil moisture regimes are based on the watertable level and the presence or absence of water that can be used by plants. Soil moisture regimes affect soil formation and the use or management of soils. Soil moisture regime classes include:

- Aridic: arid climate, usually dry. Irrigation required for crop production. Dry soils for significant periods.
- Xeric: semi-arid or Mediterranean climate. Dryland crop possible from stored soil water. Soils can be wet in winter but dry in summer.
- Ustic: semi-arid climate. Rain falls during the growing season. Generally dry in summer.
- Udic: humid climate. Soils usually moist and so irrigation is not generally required for crop production.
- Perudic: precipitation exceeds evapotranspiration in all months, but soil is not saturated for long periods.
- Aquic: soil is saturated by water long enough to cause anaerobic conditions (not visible on the map).

Soil moisture from satellites

In recent years, increasingly accurate assessments of actual soil moisture conditions have been provided by sensors on-board satellites. The image below shows soil moisture levels for Eastern Africa as mapped by the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) mission. The orange and yellow colours denote dry soil conditions and graphically illustrate drought conditions over Somalia (July is normally the rainy season). (ESA) [14, 14a]



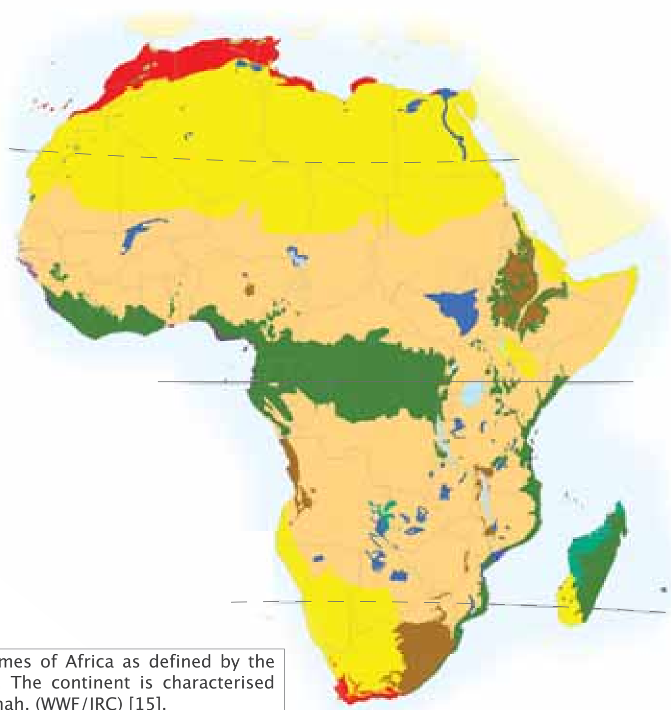
Soil-forming factor 4: Living organisms

All plants and animals (from microorganisms to humans) affect soil formation. Living organisms add organic matter - a key component of soil - through the breakdown of litter and the decomposition of roots. Microorganisms, such as fungi and bacteria, facilitate chemical exchanges between roots and the soil to produce essential nutrients. Both animals and plants allow moisture and gases to seep into deeper layers along burrows and root channels. Humans can impact soil formation through land management practices that disturb natural processes and change the chemical and physical characteristics of the soil. Cultivation practices and burrowing animals mix soil from different horizons, especially from the organic-rich surface layers. The nature of biological activity in the soil is governed by climate, topography and soil characteristics such as depth, texture, structure and chemistry (e.g. pH, salinity).

Ecoregions and biomes

Ecoregions can be defined as relatively large units of land or water containing a distinct assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land-use change. The limits of ecoregions generally follow continental boundaries or major barriers to plant and animal distribution (such as the Himalayas and the Sahara). Africa south of the Sahara Desert, including the island of Madagascar, lies in the Afrotropic ecoregion. With the exception of Africa's southern tip, the Afrotropic ecoregion has a tropical/subtropical climate. The Sahara and northern Africa lie in the Palearctic ecoregion.

Ecoregions are classified by the presence of biomes, which are major plant communities determined by rainfall and climate. Forests, grasslands (including savannah and shrubland) and deserts are distinguished by climate (e.g. tropical, subtropical, temperate) and water conditions. In addition, forests are divided into conifers, broadleafed or mixed.



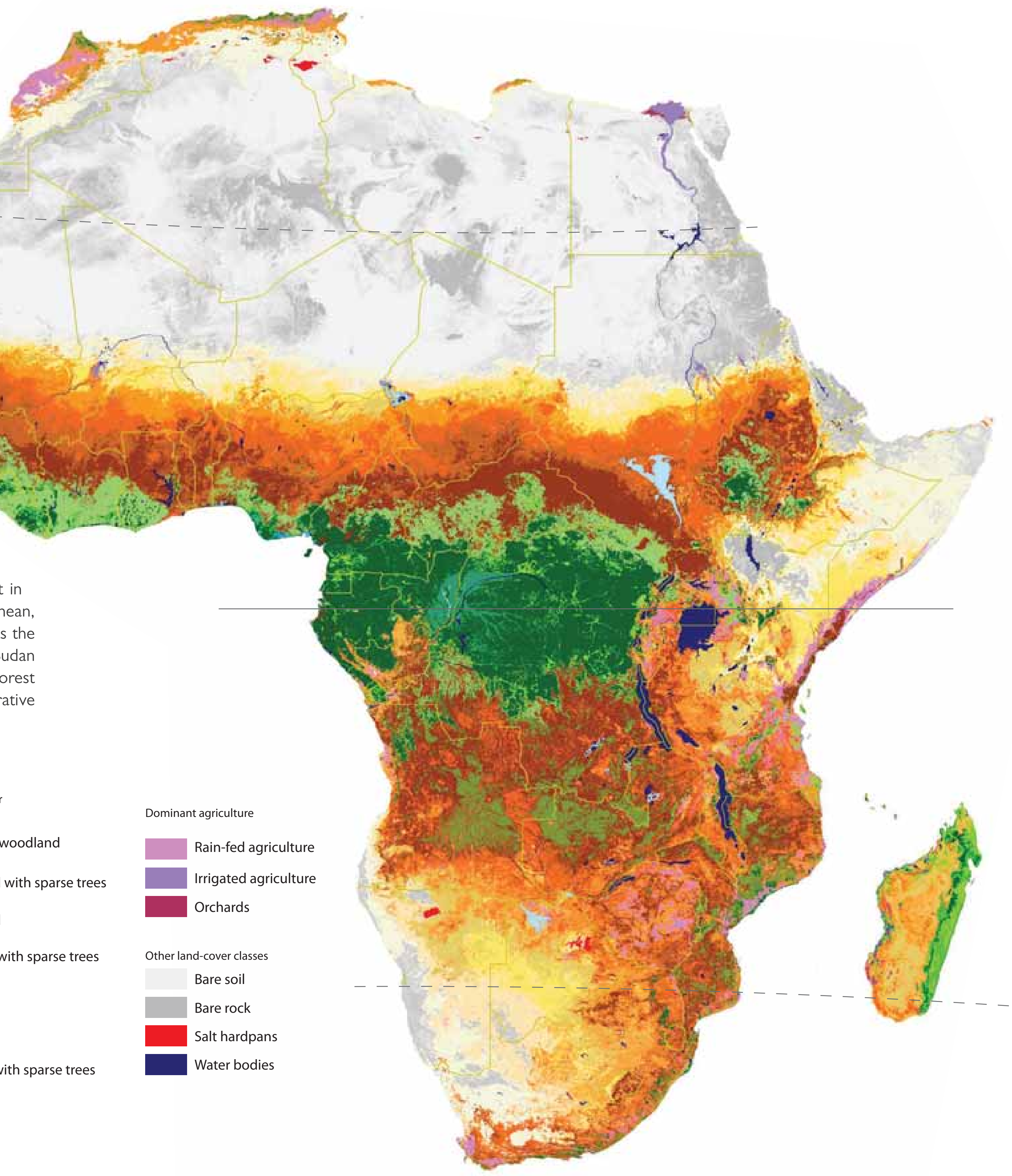
Above: Map showing the major biomes of Africa as defined by the World Wide Fund for Nature (WWF). The continent is characterised predominantly by deserts and savannah. (WWF/JRC) [15].

Below: Land cover map of Africa. This map was produced for the year 2000 using data collected by sensors on satellites. (JRC) [16, 16a]

Land cover

The term 'land cover' is used to describe the vegetation covering the surface of the planet (which can also be bare ground or unvegetated). It is important to distinguish between the terms 'land cover' and 'land use'. For example, a land cover of mixed shrubs and grass could be a park, an orchard or in an African context, savannah.

This map on the lower-right shows the principal land cover types of Africa for the year 2000 as mapped by sensors on-board satellites orbiting the Earth [16]. The map shows that the central regions are covered by extensive tropical forests (dark green) which merge to the north and south with open woodland and grasslands or savannah (brown and orange). In between, the light green areas denote a mosaic of cropland and forest that indicates the human alteration of natural vegetation patterns. With increasing aridity, the savannah grades into open and sparse grasslands (yellow colours). Where water is more plentiful, rainfed and irrigated agriculture exists (pink). These areas are particularly evident in Zimbabwe, around Lake Victoria and along the Mediterranean, East African and South African coast. The map clearly depicts the enormous extent of the vast Sudd wetlands of southern Sudan (light blue), the Okovango Delta in Botswana and the swamp forest of the Congo Basin. The distinctive red patches are the evaporative salt flats and pans of the desert margins.

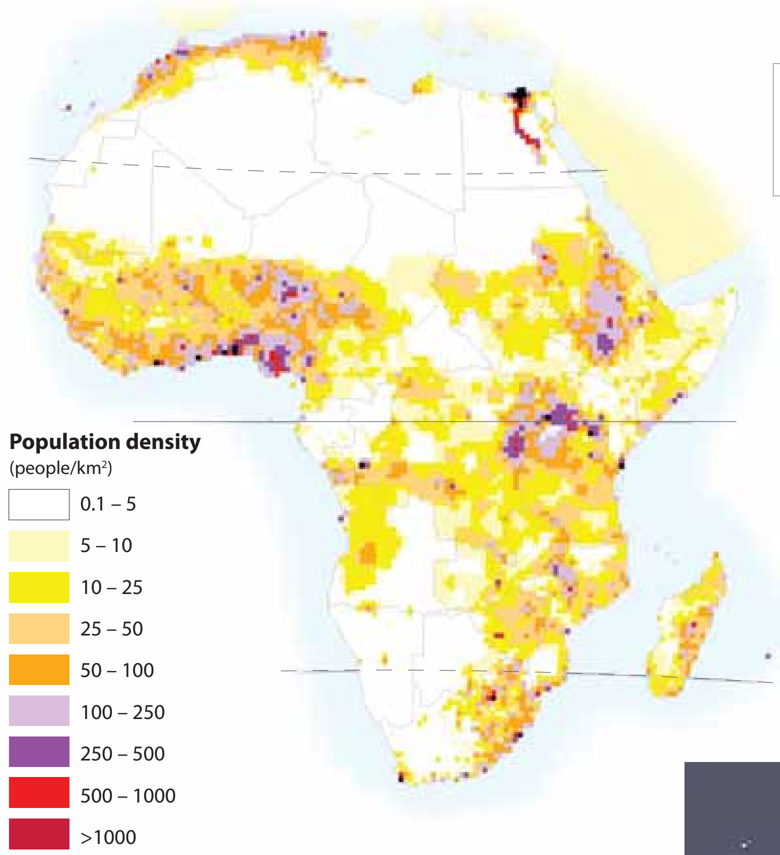


Soil-forming factor 5: Human activities

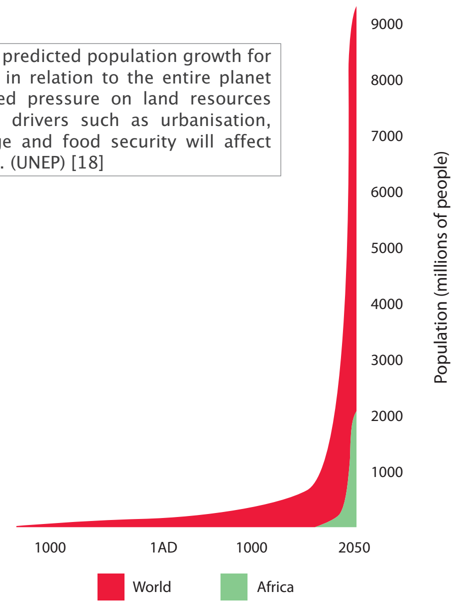
Originally, human settlement was closely dependent on climate, the availability of water, the length of the growing period and the presence of fertile soils for crops and fodder. As a consequence, the urban pattern and infrastructure network that is visible today reflects the areas that match these conditions. The map on the right shows population density for Africa (technically this is the estimated number of people living within one square kilometre). This map denotes where people are concentrated; from the less populated (white) areas to the densely populated red and purple regions. The pattern of linear settlements associated with major transport corridors is very evident.

Population density is very low in the arid and mountainous regions while the Nile Delta, the Maghrebian coast and the Gulf of Guinea are amongst the most densely populated areas on the continent (see also the adjacent map of accessibility). Population density in the centre of Cairo is over 35 000 people / km², reaching 48 000 in parts of Lagos. The most densely populated country in Africa is the island of Mauritius with nearly 600 people / km². Rwanda has close to 300 people / km² while Namibia (2 people / km²) and Western Sahara (1 person / km²) are among the least densely populated territories on the planet.

African society is rapidly changing from rural to urban, with cities and towns expanding dramatically, in terms of both population growth and extent. The sealing of rural land, agriculturally productive soils and contamination are major issues associated with urbanisation. (AJ)



Map showing the population density of Africa. The values denote the number of people living in one square kilometre. The main urban sprawls (e.g. Cairo, Lagos, Johannesburg and the northern fringe of Lake Victoria) are clearly evident as are the dense population of Rwanda and Burundi. Urban populations rely almost entirely on third-parties for food production, which in turn puts increasing pressure on rural soils. (CIESIN/JRC) [17]



Historical and predicted population growth for Africa (green) in relation to the entire planet (red). Increased pressure on land resources in relation to drivers such as urbanisation, climate change and food security will affect soil processes. (UNEP) [18]

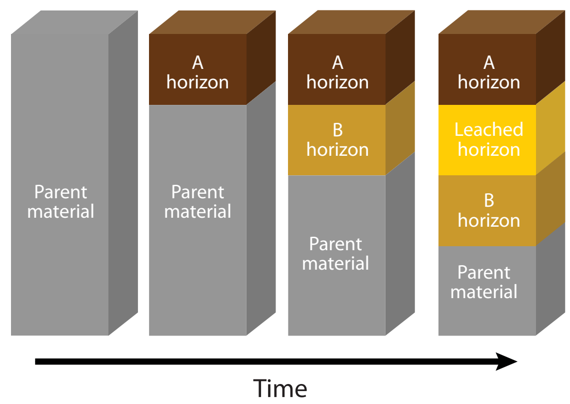
Europeans once referred to Africa as the dark continent due to vast areas of 'unexplored' land. However, this night-time satellite image **(right)** conveys a similar sense. The bright dots are lights from built-up areas. While Western Europe and much of the North African coast is glowing with night lights, the Sahara and much of south-central Africa are largely devoid of illuminated cities. It should be noted that this pattern also reflects the lack of infrastructure in many rural communities where a constant electricity supply is not available or not used for lighting. Two of the most striking features on this image are the high concentration of cities on the River Nile, along the Mediterranean coast of North Africa, the Gulf of Guinea and the urban conglomeration of Pretoria and Johannesburg in South Africa. (NASA)

Soil-forming factor 6: Time

While soils are formed through the combined effect of physical, chemical and biological processes which operate over hundreds or thousands of years, these factors rarely remain constant. Time determines the duration for which a set of factors is active. Over geological timescales, new sources of parent material can be introduced to the landscape while changes in global climate patterns are usually accompanied by changes in sea-level, erosion and deposition regimes, vegetation patterns and the shape of the landscape.

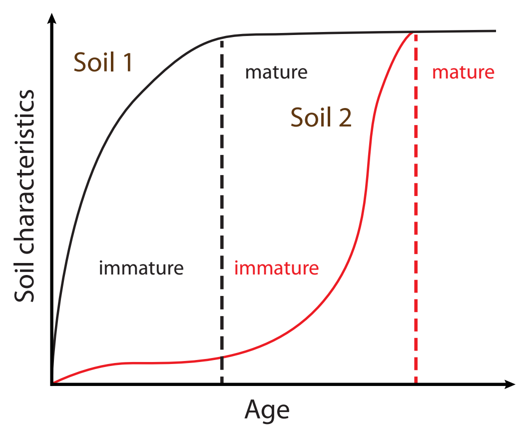
Over much shorter timescales (100 – 1 000 years), major changes can occur in the amount and nature of biological activity or hydrological conditions within a soil. Even annual fluctuations in weather patterns (e.g. drought versus above-average rainfall) or changes in the use of the land (conversion of forest to arable farming) can affect soils.

Dramatic changes in soil-forming factors can either lead to an increase in the rate of soil formation or to the destruction, or even complete removal, of the soil. Given constant environmental conditions, all soils must eventually tend towards a state of equilibrium or maturity where the rate of soil formation is equal to the rate of soil loss. However, situations may arise naturally where the rate of destructive processes exceed the rate of accumulation and retention of materials from weathering, plant growth and aerial deposition. At this point, the soil becomes vulnerable to degradation processes such as wind and water erosion.



Above: The figure shows a theoretical soil development over time in a humid environment. Unweathered parent material is subjected to weathering. The accumulation and decomposition of organic matter on the surface eventually leads to the development of an A horizon. Much later, soil processes will lead to the development of a B Horizon with accumulations of organic material, clay, iron or aluminium – often derived from the A horizon. In humid environments the upper part of the soil profile may become leached and an eluvial horizon (or E horizon) is formed. (JRC)

Below: Over time, soils settle into a steady state in which the rate of formation is equal to its rate of destruction (soil 1 and 2 develop on different parent materials). This state is referred to as being mature where soils characteristics are stable and support complex ecosystems. A key issue for land managers is how to preserve a soil while using it for crop production – an activity which inevitably changes the soil-environment balance. (JRC/LJ) [based on 6]



Young soils

In arid or mountainous areas, clear evidence of any ongoing soil-forming processes, other than the weathering of the parent material, may be difficult to find. Profile development can be negligible as a consequence of the young age and/or slow rate of pedogenic processes because of unfavourable climatic conditions for plant growth (e.g. prolonged drought, low temperatures). The paucity of altered products means that the characteristics (i.e. colour, chemistry) of the soil are very similar to those of the parent material. The development of a thin, unstratified surface horizon or subtle changes in the colour and/or structure below the surface horizon are sometimes the first steps towards the development of an A horizon. With time or changing conditions, the expression of horizons becomes stronger and the soil properties begin to differ markedly from that of the C horizon.

How old are soils?

Accurate assessments of the age of soils are very difficult to make. Since soil-forming factors continue to affect soils during their existence, evidence of earlier cycles may have been destroyed.

Ancient human artefacts found in the soil can be used to date development as long as the material has not been buried by other people! If organic matter is found at depth then a method can be used for dating its age based on the natural radioactivity present in all organic carbon matter. Alternatively, if the time that has elapsed since the last exposure of the parent material is known, then the age of the soil development can be deduced. Studies have shown that the rate of soil formation varies form very rapid (around 100 years for 2-5 cm) on volcanic ash in the warm, humid tropics to very slow (1 cm in 5 000 years) on hard rocks in cool temperate climates. A commonly quoted value is 100 years for 1 cm of soil development under permanent grasslands in temperate climates.

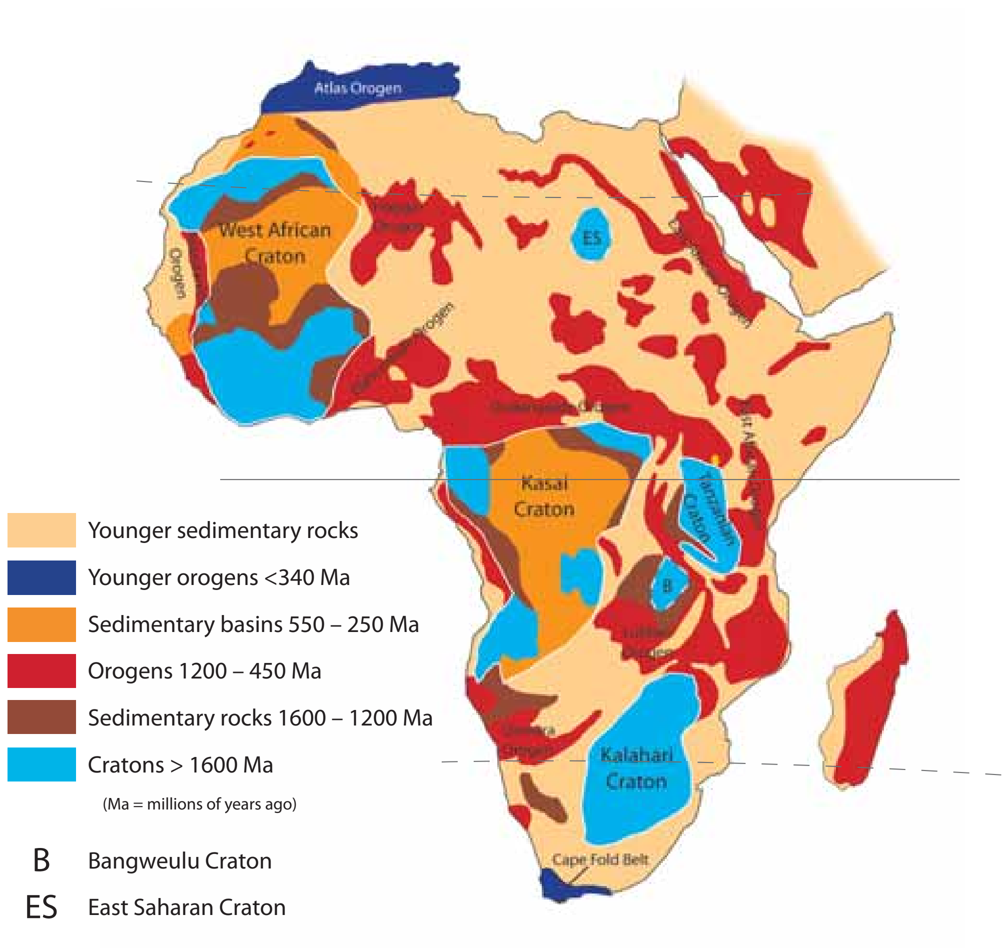
There is much debate as to the age of soils in the tropical region of Africa. Many scientists believe that some soils in the tropics (see page 31) are millions of years old. Large parts of tropical Africa have been land surfaces for 60 – 100 million years and that flat terrain has preserved old soils. Some scientists propose that the deeply weathered, iron-rich soils of the tropics, which can be up to 50 m deep, require very long timescales to develop to such a depth. Since these soils display very little textural variation or evidence of horizons and almost all clay minerals have been destroyed, then by reasoning, they must be very old.

Countering this argument is the view that soil-forming factors are operating only at the surface of deeply weathered sediments. In this way, the soil-forming factors are dominated by current climate and vegetation conditions. Given this argument, the soils must be relatively young!

In reality, the sediments of tropical Africa contain evidence of several soil-forming phases, often reflecting changing climatic conditions.

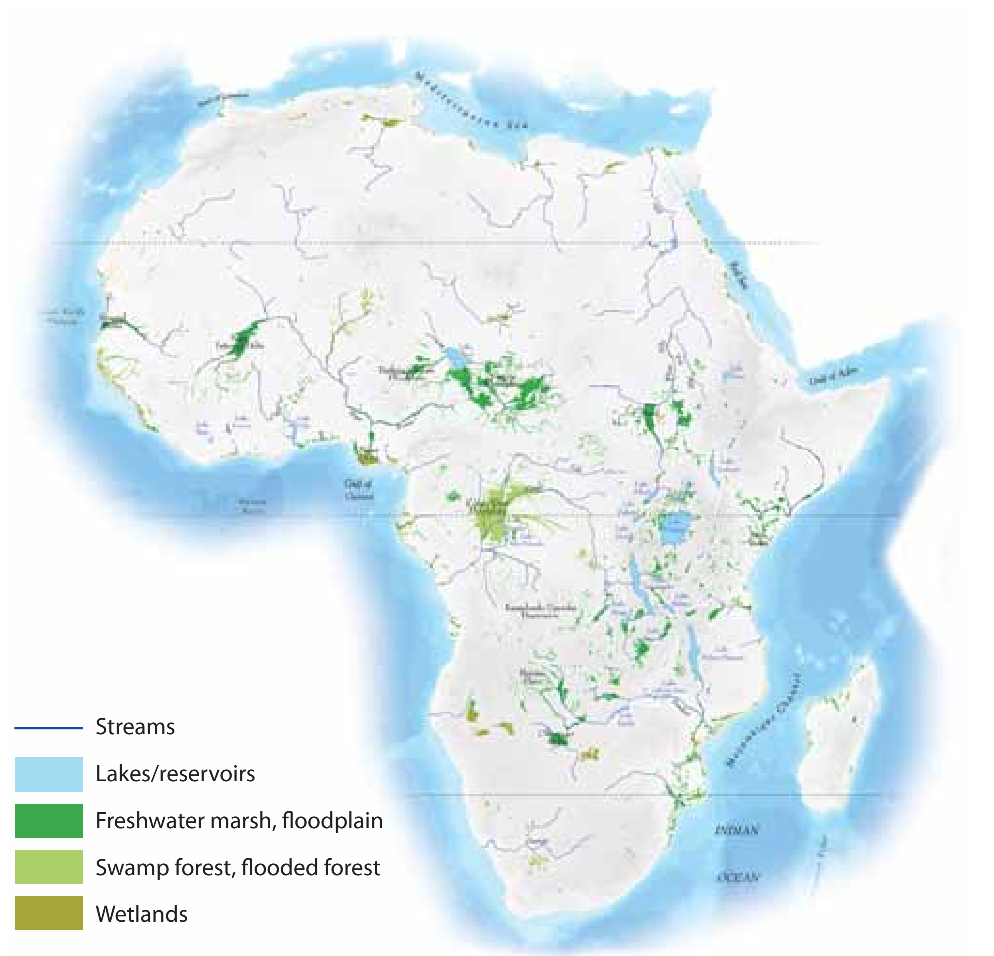
Additional information

Geological structure



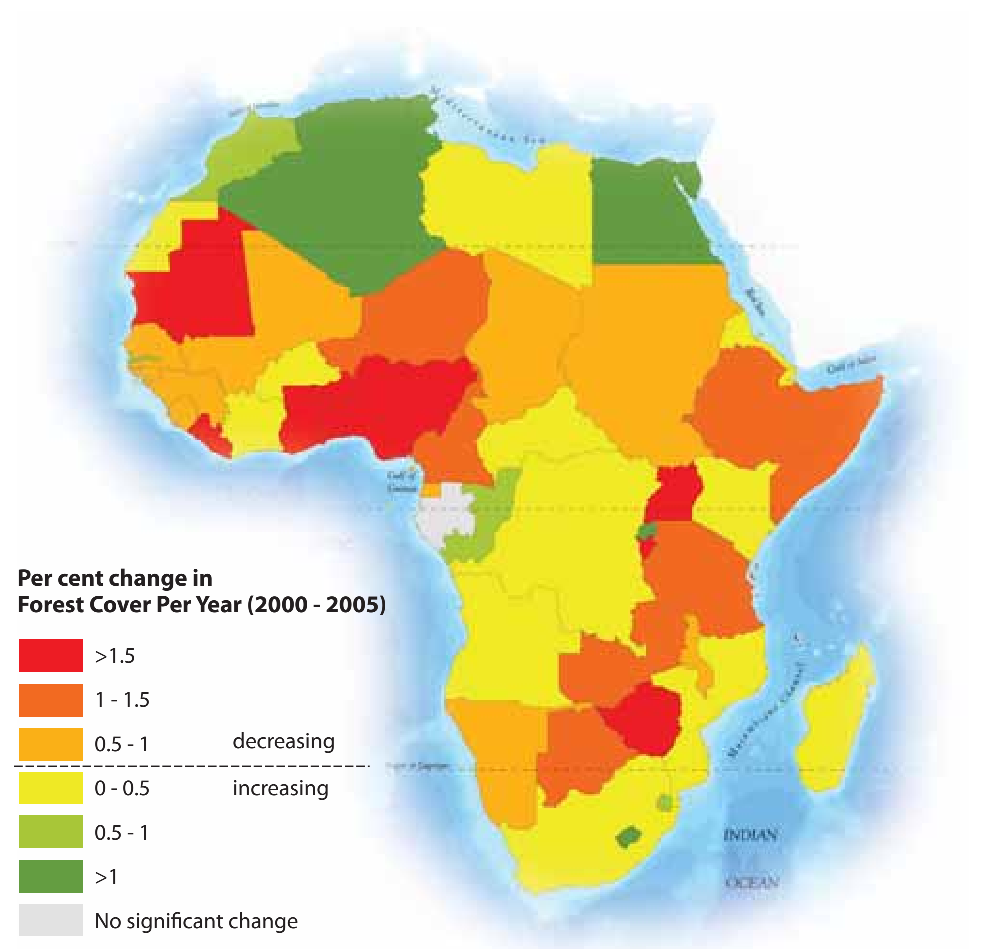
This map shows a simplified view of the geological structure and tectonic features of Africa, which in turn define cycles of erosion and soil formation. Orogens are zones of highly deformed rock caused by the collision of tectonic plates, the primary mechanism by which mountains are built on continents (the Atlas Mountains in North Africa were created by the coming together of the African and Eurasian plates). The age range denotes when the event took place. Cratons are an old and stable part of the continental crust and are generally found in the interiors of tectonic plates. Composed of ancient crystalline rock, cratons are often referred to as shields. Parts of the Kalahari Craton (in Limpopo, South Africa), have been dated to around 3.6 billion years - the oldest piece of crust on the planet. As may be seen, large parts of the African surface have remained stable for millions of years. (USGS) [19, 8]

Surface water bodies



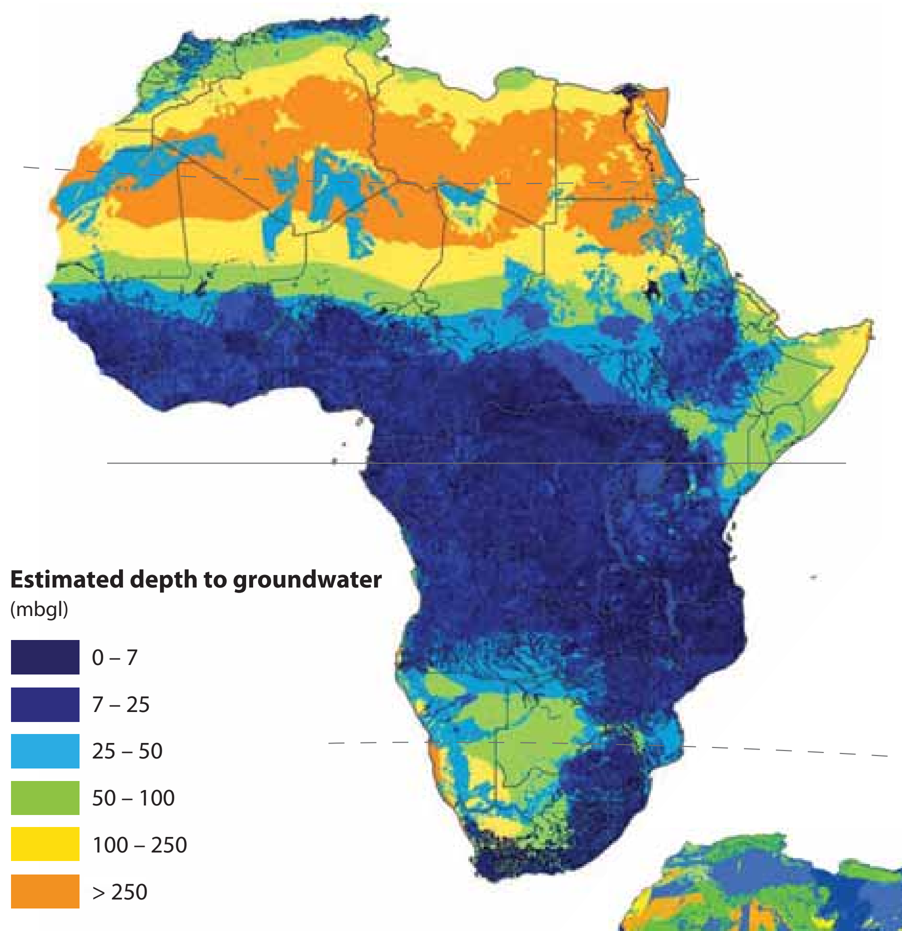
The map shows the surface hydrological features (rivers, lakes and wetlands) of Africa. The humid and sub-humid regions of Africa possess abundant water resources in the form of seventeen large rivers and 160 lakes with a surface area greater than 27 km². The Nile is the world's longest river and only the Amazon discharges more water than the Congo. Many rivers show dramatic seasonal variability. East Africa has numerous lakes including Lake Victoria (3rd largest in the world by area and largest tropical lake in the world) and Lake Tanganyika (3rd largest by volume and 2nd deepest lake on Earth). Surface runoff in Africa is, on average, much lower than the average precipitation as a result of high evaporation and evapotranspiration. Groundwater provides nearly two-thirds of the drinking water on the continent, and an even greater proportion in northern Africa. Land that is regularly saturated by surface water or groundwater is important from an ecological perspective, but in Africa, wetlands cover only about 1% of the continent's total surface area. The watersheds of the major African rivers is presented on page 22. (UNEP) [20]

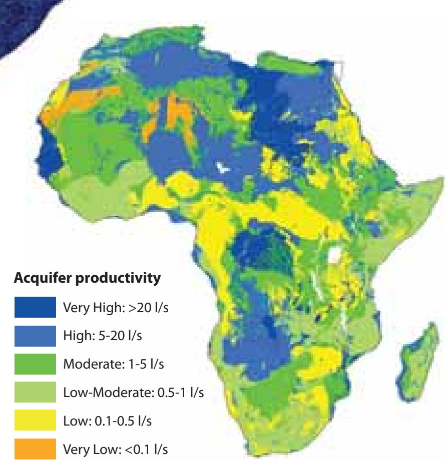
Deforestation and land cover change



Map showing the change in forest cover by country across Africa between 2000 and 2005 as measured by earth observation satellites. The results show that apart from a few exceptions, forest cover displays a marked decreasing trend across the continent. Strongly affected countries are Benin, Ghana, Liberia, Mauritania, Togo, Uganda and Zimbabwe. The main drivers are commercial logging, clearance for large-scale agricultural development and small-scale subsistence farming. In areas where forest has been cleared, a marked increase in soil erosion has been observed. More than 70% of Africa's remaining rainforests are located in the Congo Basin countries of the Democratic Republic of Congo, Congo and Gabon and cover and estimated 1,875 million km² (see also page 152). (UNEP/FAO) [21]

Groundwater resources



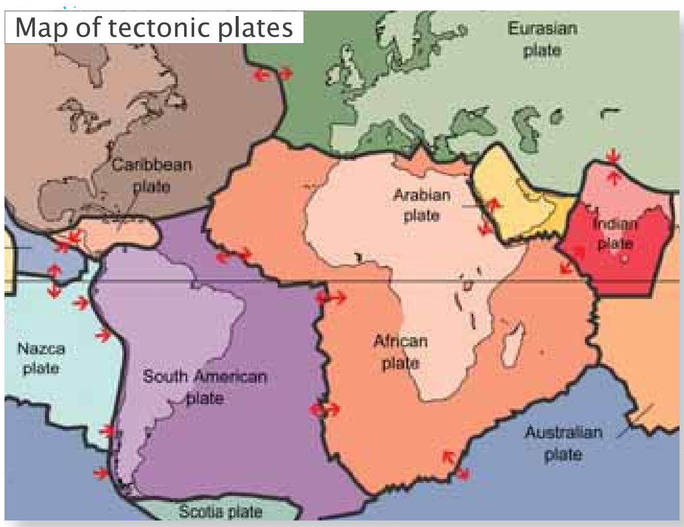


Above: Map showing the estimated depth to groundwater in metres below ground level (mbgl), based on rainfall, aquifer type and proximity to rivers.

The **inset** map (**right**) is a groundwater productivity map which indicates what borehole yields can reasonably be expected in different hydro-geological units.

Irrigation by groundwater is a critical aspect for agriculture in many parts of Africa but if incorrectly managed, can lead to the build up of salts in the soil. The maps show that while most parts of Africa have relatively shallow aquifers, the water supply is low or moderate. Conversely, the Sahara is underlain by extensive reserves of groundwater but at considerable depth, the exploitation of which raises both technical and environmental concerns. (BGS) [22]

Africa – the political view



Above: Political map of Africa. At this scale, national boundaries are only indicative. Political boundaries are only indicative. (LJ);

Inset: Map showing the extent of the African plate and associated tectonic elements. (USGS);

Below: A map of the major river basins of Africa. Many river basins have no outlet to the sea. (JRC)

From a geological perspective, the African tectonic plate is significantly larger than the visible continental land mass (see inset above). Originally the Arabian plate was part of the African plate but it is now separated by the Red Sea Rift. Red arrows on the map indicate the current direction of tectonic movement. The northward collision of the African plate with the Eurasian plate is responsible for the formation of the Alps, volcanoes in Italy and earthquakes in southern Eurasia.

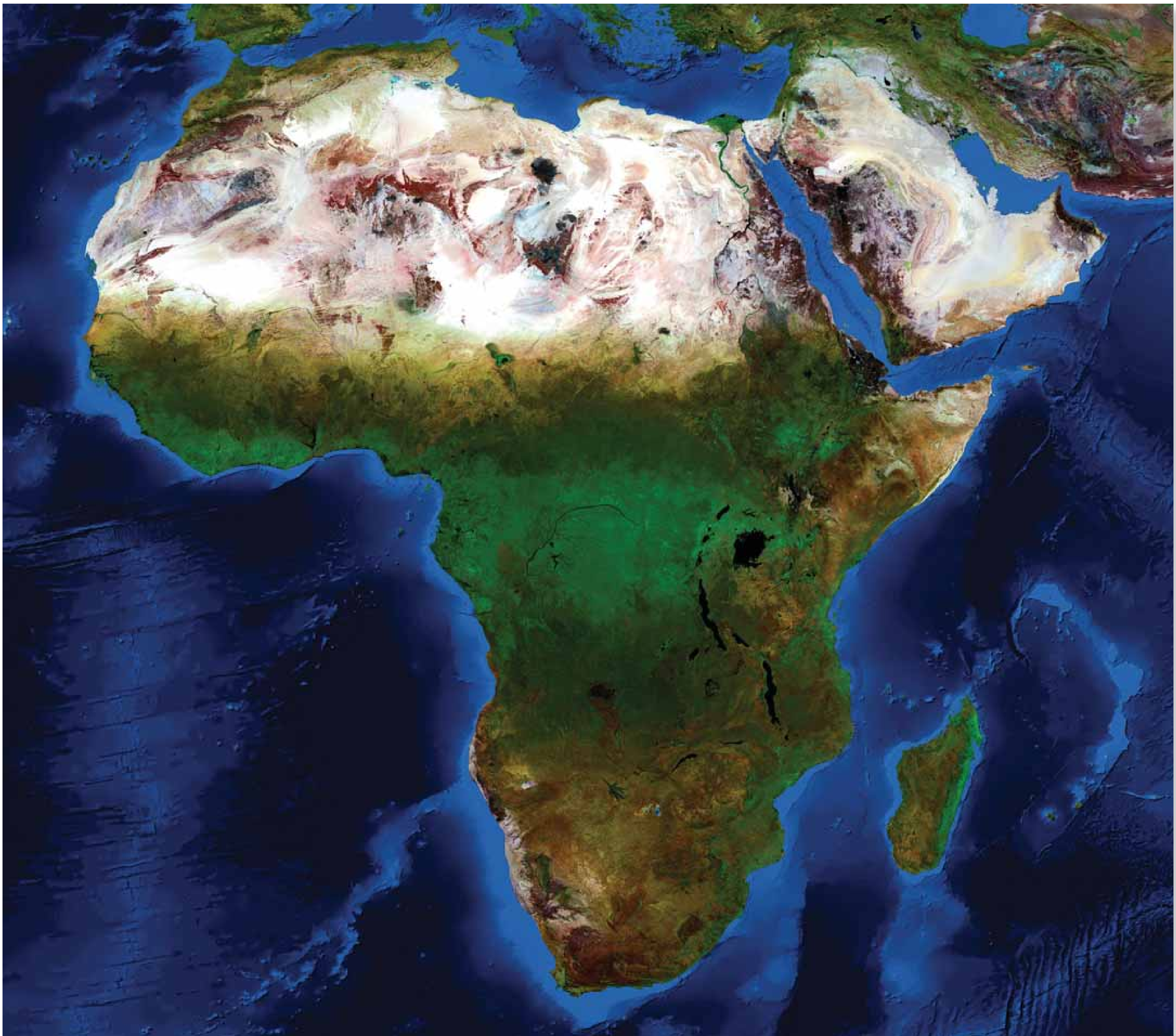
For the purposes of this atlas, soil information is provided for the entire continental land mass of Africa and all islands located on the African plate (see map spreads on pages 80-127 and summary texts on pages 158-161). This includes Malta, parts of France (Réunion, Mayotte and a small number of uninhabited islands around Madagascar), Italy (Lampedusa and Lampione), Portugal (Madeira and surrounding islands) and Spain (the Canary Islands, the Autonomous Cities of Ceuta and Melilla, and small islands off the coast of Morocco). No information is provided for the volcanic Mid-Atlantic Ridge islands of St Helena, Ascension and Tristan da Cunha Socotra (administrated by the United Kingdom) nor for the island of Soqotra, which is part of the Asian state of Yemen. Although the Sinai peninsula is considered geologically as part of Asia, it is included in the atlas as it is part of the Egyptian state.

In terms of geographic area, Africa is the planet's second-largest continent covering an area of 30.3 million km^2. Africa's largest country is Algeria while the smallest is the Indian Ocean archipelago of the Seychelles. The smallest country on the continental mainland is The Gambia in West Africa.

With just over a billion people, it is the second-most populous continent in the world and accounts for just over 14% of the world's human population. Politically, Africa consists of the fifty-four states that are fully recognised by the United Nations and the Sahrawi Arab Democratic Republic which is a member of the Africa Union (Morocco is not currently a member of the AU). Of these fifty-five states, forty-nine are found on the actual continent while six are island nations.

Nigeria is by far the most populous state with 166 629 000 inhabitants while the Seychelles are home to only 87 000 people spread over 115 islands. The population of most African countries is growing by more than 2% per year, with Niger at 3.6% (all population estimates are from the UN for 2012).

Africa – the real view?



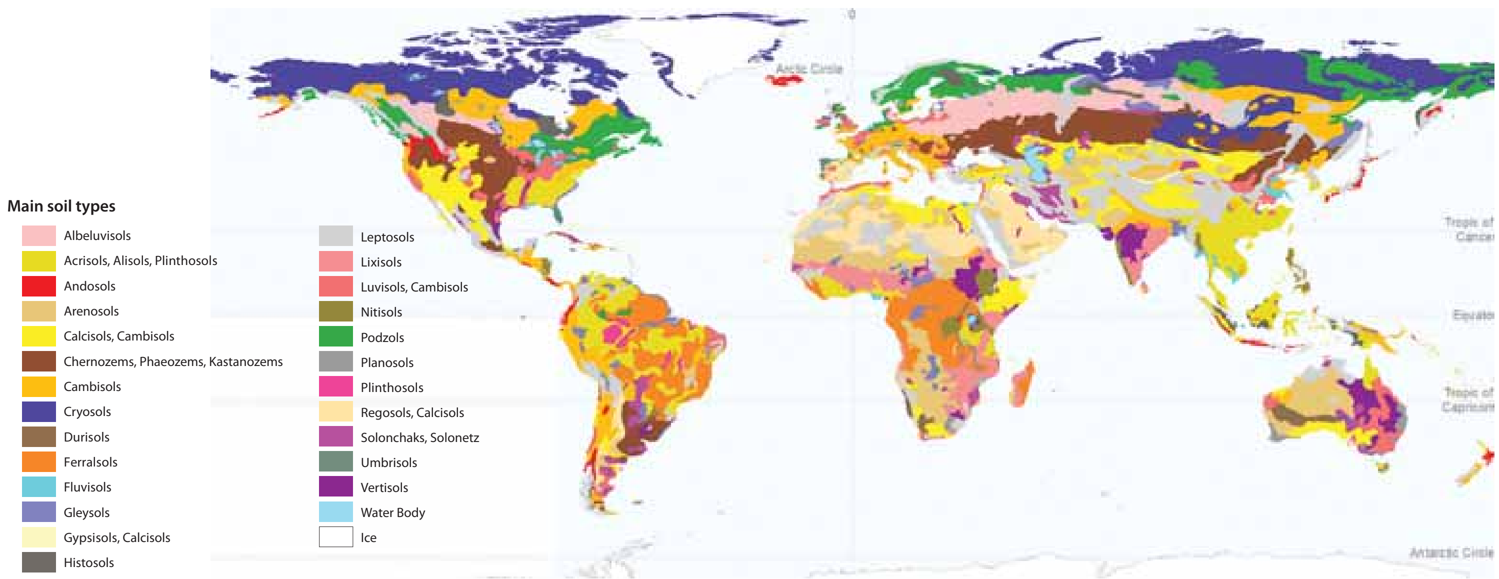
The striking image shown **above** is a view of Africa as seen from space. This overview has been made up of dozens of smaller, cloud-free segments acquired by the NASA MODIS sensor (Moderate Resolution Imaging Spectroradiometer) from June to September 2001. The MODIS sensor is carried on-board a satellite that orbits the Earth every 1–2 days at an altitude of 705 km and is an example of remotely sensed data, which, through computer enhancement, can be viewed as an image. In this case, the image is displayed in near true colour which means that it appears almost as if viewed by a person in space. Green tones correspond to vegetated areas: the tropical rainforests in the Congo Basin and on the east coast of Madagascar are very evident, as are the intensively cultivated soils of the Nile Delta, and the vegetation around Lake Chad and the highlands of Ethiopia. Darker green areas around the tropical forests denote a mosaic of woodland and cultivated land. The mottled brown/light-green areas to the north and south of the Equator denote a reduction in tree cover and the increasingly open grassland environments of the savannah. The distinctive, isolated dark-green area in Botswana is the Okovango Delta.

In the arid, unvegetated regions of the deserts, white and bright yellow colours correspond to sand seas while the dark red (almost blackin some cases), brown and orange hues indicate bare rock surfaces – the mountain ranges of Ahoggar, Tibesti and the Aïr Massif are strikingly apparent in the Sahara. The movement of sand in relation to prevailing wind patterns is noticeably apparent.

The almost black features in central Africa are water bodies, with the path of the East African Rift Valley being clearly delineated by its lakes. The path of the Nile and Niger are clearly visible as are the numerous tributaries of the Congo. The line of turquoise areas running from Tunisia to Algeria (and also south of the Okovango) are salt lakes. At this scale, urban areas are difficult to visualise.

The spectacular details in the ocean are derived from the General Bathymetric Chart of the Oceans. (NASA/JRC)

The soils of Africa in a global context



Map showing the broad distribution of soil types across the world according to the WRB Classification and Correlation system (see pages 50 – 61). The different colours indicate variations in the chemical, physical, and biological characteristics of soils which, in turn, are a reflection of the principle soil-forming factors described on the preceding pages. The map clearly shows that Africa has a unique pattern of soils that is not replicated on the other continents. Lacking the organic-rich peats, Podzols and permafrost-affected soils of the northern latitudes, the largely tropical African continent is nevertheless characterised by huge contrasts. The weakly developed soils of the Sahara, Kalahari, Namib and Horn of Africa appear to surround a central core of tropical soils reflecting differences primarily in climate and parent material. The prominent Gleysols of the vast African wetlands on the Niger, Congo and Zambezi Rivers denote seasonally waterlogged soils while the large expanse of heavy clays of the Vertisols in Nile Valley in Sudan is very evident. (FAO/ISRIC/JRC) [23]

Soil-forming processes

Principle processes

The specific properties of an individual soil are determined by pedological processes that operate during its lifetime. These biological, chemical and physical actions add, transform, move (translocate) and destroy or remove material within the soil. It is important to recognise that soil-forming processes can evolve and change over time in response to factors such as climatic variability and land use. Due to their old age, many African soils exhibit several distinct and different phases of soil formation.

Weathering

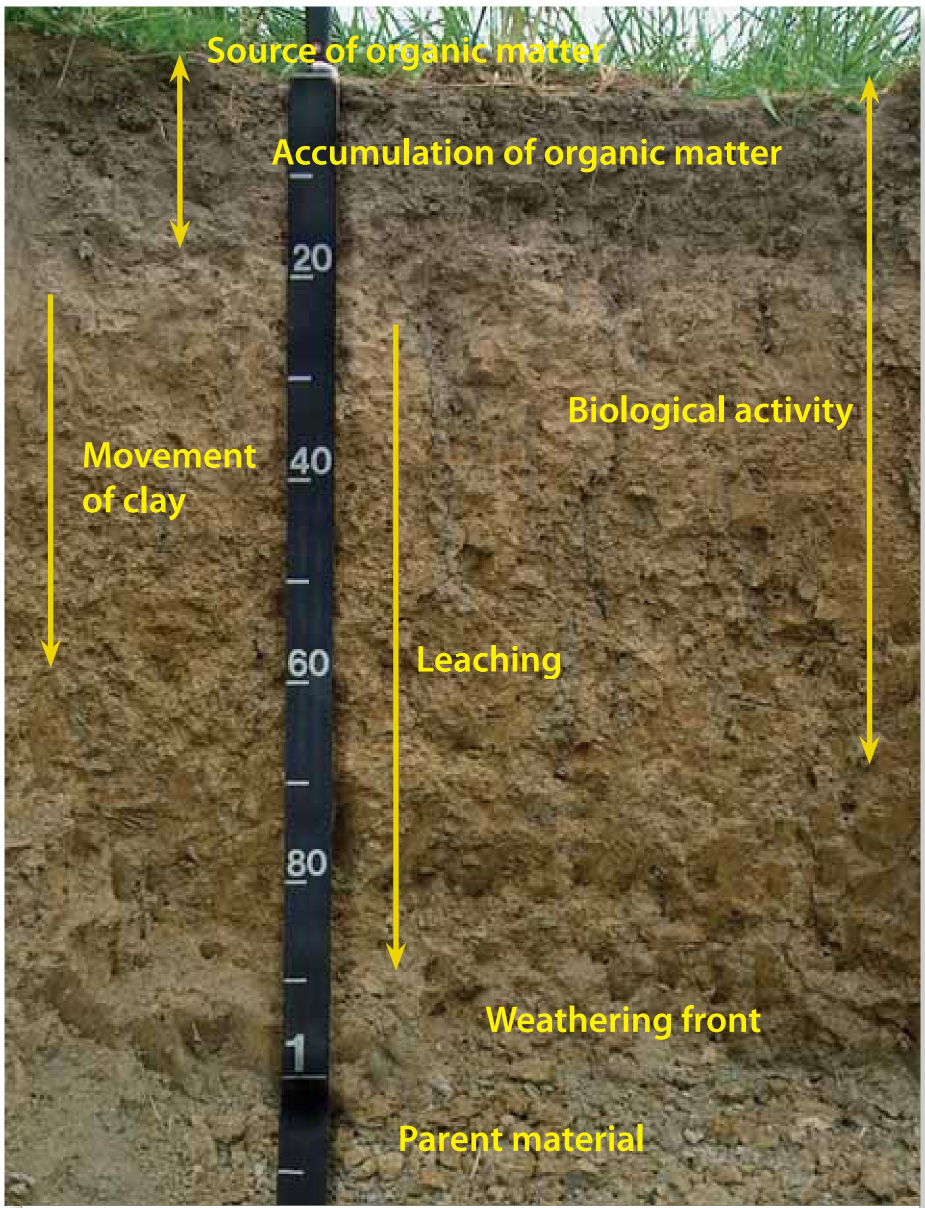
Below the soil we usually find solid rock or unconsolidated sediments in (or on) which the soil has developed (see page 14). In reality, all sediments are derived from solid rock by a process known as weathering. Weathering proceeds by a physical destruction of the rock structure which in turn facilitates chemical changes to the constituent minerals.

In principle, there are two main types of weathering: physical and chemical. Some people also consider biological weathering but, in reality, it is a manifestation of physical and chemical actions (see below).

Physical Weathering

In physical weathering, rocks disintegrate without changing their chemical composition. Typical examples of these processes are the splitting of rocks by the daily warming of the sun and cooling during the night (typical of desert environments) or by the repeated freezing and thawing of water (when water freezes, its volume increases by 10%, causing tremendous pressures if it occurs in confined spaces such as crevices in rocks).

Physical weathering produces a layer of loose material which covers the underlying solid rock. This material is known as regolith and can vary from a few milimetres to tens of metres thick. Regolith layers in some parts of west Africa have been found to be more than 150 m thick. There is often a sharp boundary between the bottom of the regolith and the bedrock. This narrow zone is known as the weathering front and is the focus of active weathering.



A schematic of key soil-forming processes. The dark colour of the upper part of this soil profile indicates that significant amounts of organic matter have accumulated in the topsoil through the decay of vegetation and root material. The lighter colour between 20 and 40 cm is due to a combination of the leaching of mobile iron and loss of clays by percolating rainwater. In the subsoil, the iron has coated soil particles with a thin, reddish film. The bedrock from which the soil has developed and the weathering front is clearly visible at the base of the profile. Biological processes are generally more active in the topsoil. (EM)

The destruction of bedrock through both physical and chemical weathering is clearly visible in this photograph from South Africa. The red rock is a dolerite dyke that has intruded into granite (visible to the left). Weathering processes have caused blocks of granite to break away while the dolerite breaks down more easily to produce the distinctive red coloured finer material that is accumulating at the foot of the slope. It is very evident that the dolerite is weathering more rapidly than the granite. The dolerite is receding into the cliff face and approximately 15 cm of soil has developed above it while bare rock is still visible on the surface of the granite. (EM)

Minerals vs Nutrients

A mineral is a naturally occurring solid substance formed through geochemical processes with a characteristic chemical composition. Rocks are composed of several minerals.

Nutrients are chemical elements required by organisms to live and grow. Nutrients can be produced by the organism or must be taken in from its environment. Plants absorb nutrients from dissolved minerals in the soil which, in turn, are consumed by herbivores and then by the people who eat the herbivores. In this way, minerals move up the food chain.

Chemical Weathering

Chemical weathering is a gradual and constant process. It is driven primarily by the reaction between water or an acid and elements within the parent material which lead to the creation of secondary minerals from the original compounds present in the rock. Chemical weathering is much stronger if temperatures and humidity are both high (e.g. in the humid tropics).

Water is the key factor in chemical weathering. Most people are unaware that rainfall is slightly acidic with a pH of around 5.6 in unpolluted environments. Atmospheric carbon dioxide dissolves in the rainwater to produce a weak carbonic acid. Some minerals, due to their natural solubility (e.g. evaporites such as highly soluble salts and gypsum) or inherent instability relative to surface conditions (e.g. primary silicate minerals such as feldspar, mica, augite, hornblende and olivine), will slowly dissolve to form secondary products such as clay minerals (e.g. kaolinite, illite, vermiculite and smectite), iron and aluminium (hydr)oxides, carbonates and nutrients such as calcium and potassium.

One of the most well-known solution weathering processes is de-calcification which occurs on parent material such as limestone and chalk that are rich in calcium carbonate. Rain combines with carbon dioxide or an organic acid to form a weak carbonic acid which then reacts with calcium carbonate in the limestone to form calcium bicarbonate, which is then removed. This process can be even stronger if gases such as sulphur dioxide and nitrogen oxides are present in the atmosphere. These oxides react in the rainwater to produce stronger acids with a pH as low as 3).

Water molecules can break up into positively charged hydronium (H_3O^+) and negatively charged hydroxyl (OH^-) particles (see Glossary for ion and cation). These small and mobile particles can actually penetrate the crystal lattice of silicate and carbonate minerals. Those with positive charge upset the balanced state of the mineral in question causing various cations to be released into the soil.

This process is known as hydrolysis and is one of the underlying factors of soil fertility (see page 32).

Another chemical process involves the simultaneous loss (referred to as oxidation) and gain (referred to as reduction) of electrons in substances. These exchanges are referred to as redox reactions. As materials become oxidised, the unbalanced charge will degrade a material's structural composition.

Biological weathering is caused by the activities of living organisms and has both physical and chemical aspects. Examples of physical biological weathering include the loosening of rock by roots growing into cracks and burrowing creatures such as termites that mix or churn the soil.

Chemical biological weathering can be caused by bacterial activity or by strong organic acids from plant roots or litter. A recent study demonstrated a 3 – 4 fold increase in weathering rate under lichen-covered surfaces compared to recently exposed bare rock surfaces. Biological weathering factors in Africa are highly significant.

A clear example of a weathering front on limestone in Tigray, Ethiopia. The photographs shows the breakdown of the underlying bedrock along vertical joints and horizontal bedding planes. (JD)

Common processes in humid conditions

Many parts of Africa are characterised by a climate that provides a precipitation surplus during some parts of the year (i.e. when rainfall is greater than evaporation rates). This surplus fills up the spaces or voids in the soil, which might have been emptied during the dry season, and then percolates down through the soil body to accumulate as groundwater. In doing so, the water drives three important soil forming processes:

1. Leaching

When water passes through the soil, it dissolves soluble salts (such as chlorides, nitrates, sulphates and carbonates) and flushes them, together with organic and chemical solutes, into the deeper parts of the soil. In the drier climates, these salts can be re-precipitated, for example, as a calcium carbonate-rich horizon in the subsoil. In more humid regions, significant amounts of materials can be completely removed from the soil by leaching.

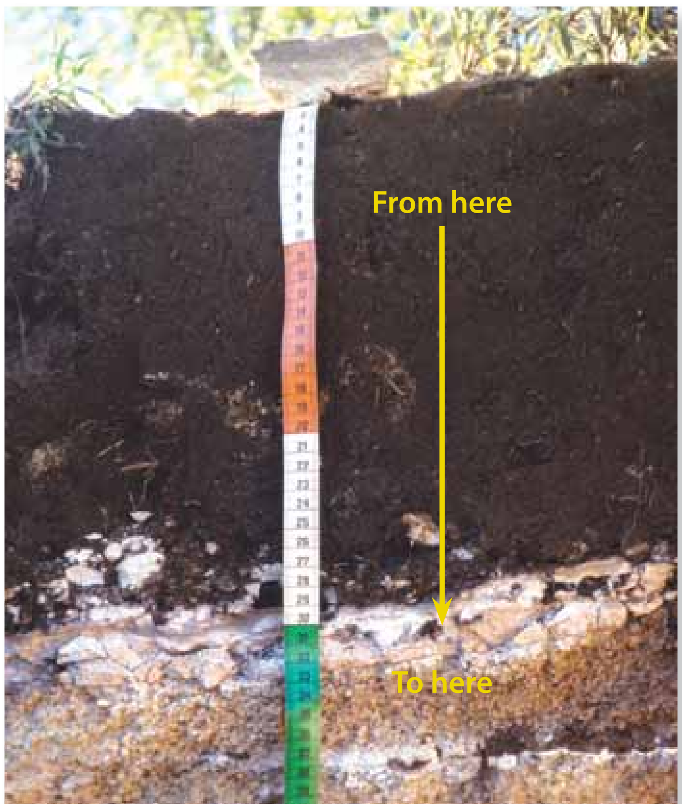
This loss of mineral and organic solutes due to percolation is known as leaching. The rate and extent of leaching depends on two factors:

- the mobility of an element, which in turn is based on its solubility in water and the effect of pH on that solubility – chlorides and sulphates are very mobile while titanium is insoluble even at a pH of 2.5;
- the rate of water percolation, which in turn depends on climate, soil texture and structure, porosity and the slope of the ground – in dry regions, even the most mobile compounds (e.g. sodium chloride) tend to stay in the topsoil and eventually give rise to saline soils.

As humidity levels increase, losses of salts, organic compounds and silica in the topsoil increase and the soil is regarded as being leached.

Leaching is a major controller of soil fertility. As long as calcium carbonate is present, the pH of the soil will be above 7 (see page 11) and the soil will often be whitish or light coloured. When the calcium carbonate is dissolved and leached away, the pH will drop and calcium, magnesium and sodium will be released from the surfaces of clay minerals and humus to be replaced by hydrogen and aluminium. Unless there is a change in the soil-forming factors or there is human intervention, the pH of soil will fall below 7 and under such conditions the soil is referred to as acid.

Highly acidic soils are not very suitable for the cultivation of food crops. Such soils will require the addition of calcium carbonate (a practice known as liming) in order to raise the pH to a more acceptable level for plant production. A reduction of pH below 5.5 can cause a release of aluminium cations in the soil solution, which is toxic for some plants, crops and nearby water bodies.



A leached soil profile from Kenya. In this soil, carbonates have been leached from uppermost 30 cm of the topsoil which is represented by the dark, humus-rich surface horizon. The white layer below 30 cm shows the accumulation of the leached carbonates deeper in the soil (OS).

In some instances, immobile elements can be leached when they are combined with organic compounds (e.g. organic and amino acids) derived from the humification of litter or from soil microorganisms. This process, known as cheluvation, is an important mechanism for increasing nutrient availability to plants. Chelates are very important in micronutrient management.

2. The movement of clay particles

A common soil-forming process is the movement or translocation of clay particles from one soil horizon to another. This involves the mechanical transfer (illuviation) of clay particles from the upper part of the soil by percolating water and their re-deposition deeper in the soil on the surfaces of soil particles or in soil pores and cavities.

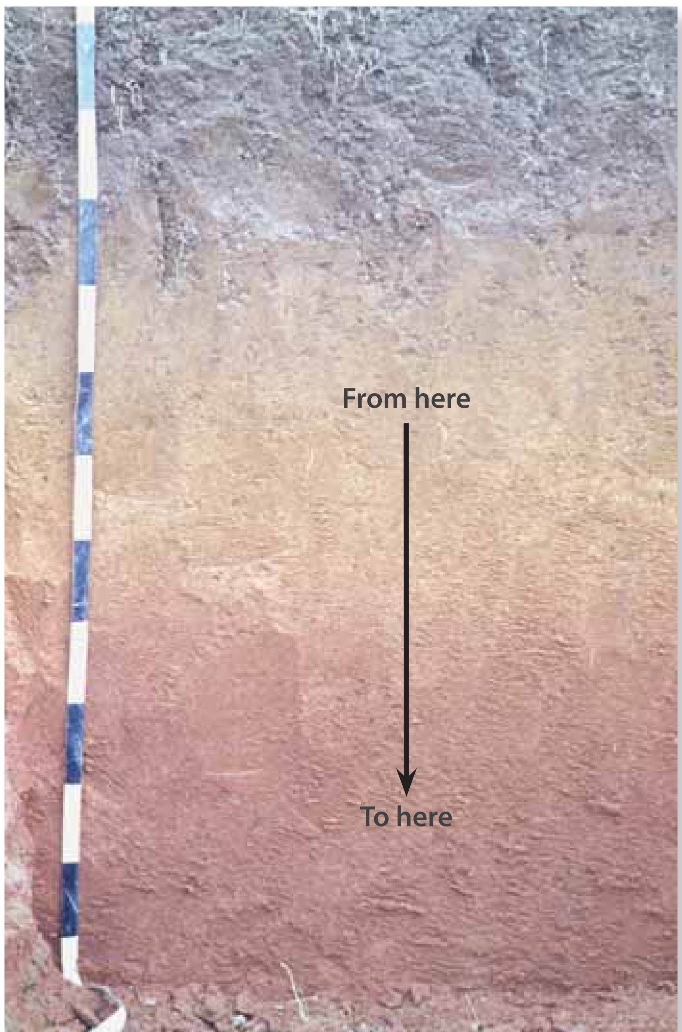
This process is dependent on the soil texture, structure and chemistry. If a continuous and coarse pore system exists in the soil, percolating water can then transport the clay particles downwards. Such conditions will develop as the soil shrinks and cracks during dry seasons. The clay will accumulate where the cracks end and water movement almost ceases or where the water penetrates into the dry aggregates and the clay particles are filtered at the ped surfaces forming clay layers or skins called cutans or argillans.

Another process that can lead to low clay content in the topsoil is raindrop erosion where splashes move the finer particles down the slope leaving behind silt and sand. This process is believed to be widespread and appears to be enhanced by shifting cultivation practices on sloping terrain.

3. Clay destruction

A significant soil process is the destruction of clay. The leaching of base cations leads to the build up of hydrogen ions on clay minerals and organic matter. This state is unstable and leads to the eventual disintegration of the crystaline structure of the clay, releasing aluminium and silica in the process.

As a result, the soil exhibits less clay and a lower pH in the topsoil and subsoil immediately below the topsoil than in the main part of the subsoil. Similar clay distribution can be found in soils where the clay in the topsoil has been redistributed rather than being destroyed (see below).



This profile from South Africa illustrates the movement of clay particles from the topsoil to the subsoil. The photograph clearly shows an upper grey layer (0 – 25 cm) which is a ploughed horizon where the soil has been mixed by cultivation. Directly underneath is a light-toned layer (between 25 – 70 cm) resulting from the destruction and removal of brown and red coloured clay particles. The darker coloured subsoil (> 70 cm) reflects the accumulation of clay particles from above. This process is known as illuviation. (ISRIC)

Clay

In English, the word 'clay' can have three distinct meanings:

i A soil particle, less than 2 μm in diameter;

ii A textural class containing more than 40% clay particles and less than 45% sand and less than 40% silt;

iii A naturally occurring material composed primarily of fine-grained minerals, which is generally plastic at appropriate water contents that will harden when dried or fired. Although clay usually contains phyllosilicates, it may contain other materials that impart plasticity and harden when dried or fired.

This profile illustrates the initial stages of soil formation. The development of soil structures and changes in colour are the only apparent pedogenic processes. This example from the Usambara Mountains in Lushoto, Tanzania shows a thin accumulation of organic matter on the surface and the leaching of iron (lighter patches). Such soils are widespread in Africa, especially in recently deposited parent material or in regions that have been tectonically uplifted. (JD)

Podzolisation

Given a specific combination of humid climate, quartz-rich, coarse-grained parent material and particular vegetation characteristics, then a characteristic soil forming process known as podzolisation can occur. Soluble organic substances released during the decomposition of plant litter can bind with iron and aluminium oxides in the soil and, given suitable chemical conditions, be leached from the topsoil. Percolating water redeposits these elements, together with organic matter, deeper into the soil, leaving behind a zone of bleached, immobile sand grains. The redeposited mix of organic matter, iron and aluminium can form a massive (hardened or cemented) horizon which acts as a barrier to the passage of organic matter and roots. Over time, organic matter accumulates on this obstruction where a dark, humus-rich sub-surface horizon develops. Precipitating iron can give a uniform orange-red colouration to this horizon.

The end product of this procees is a soil type known as a Podzol which is characterised by the presence of a subsurface deposition horizon (known as a spodic horizon). The exact characteristics of the Podzol depend on the relationship between the parent material, moisture conditions and vegetation type (see page 59).

While Podzols are found on all continents (and predominantly in the temperate and boreal regions of the Northern Hemisphere), they are generally rare in Africa. Tropical Podzols occur in two distinct ecological situations. The first one coincides with thick deposits of quartz sands in the lowlands; the second one is characterised by a cool isomesic temperature regime that prevails at high elevations in areas that have often been influenced by volcanic ash. The cool tropical Podzols are typical of mountain slopes that are hit by clouds producing orogenic rains (e.g. DR Congo, Zimbabwe and South Africa).

Soils processes under a wet tropical climate

A significant part of central Africa possesses a humid tropical climate where constant high temperatures (average annual temperature is around 26°C), copious rainfall (over 2 000 mm annually) falling daily and high humidity occur throughout the year. In addition, much of tropical Africa is characterised by old, geologically stable, shield areas that have been deeply weathered. Under such conditions, chemical weathering, leaching and translocation combine to produce a number of distinctive soils where the geology of the bedrock determines the underlying chemical properties of the soil.

In summary, the soils of the wet tropics are old, characteristically red or yellow in colour, and strongly leached. They are deep, finely textured, contain no more than traces of weatherable minerals, have low-activity clays (see page 27), less than 5 percent recognizable rock structure and gradual soil boundaries. The most typical divisions are:

• soils with a ferralic horizon

In deeply weathered sediments, a combination of high soil temperature and intense percolation, dissolve and remove all weatherable primary minerals from the soil body. Less soluble compounds, such as iron and aluminium oxides, the clay mineral kaolinite and coarse quartz grains, remain behind. This process eventually leads to the formation of a ferralic horizon. High concentrations of the iron oxide hematite give a distinctive red colouration to the soil while in more temperate conditions, goethite tends to dominate giving soils a more yellow colour. To be effective, the process requires low soil pH, geologically stable land surfaces and basic parent material containing abundant levels of iron and aluminium in the form of easily weatherable minerals but little silica (the process is much slower in acidic parent material).

Clay content and texture are relatively constant with depth due to the mixing of the soil by biological activity (primarily termites). Soils matching these characteristics are referred to as Ferralsols (see page 53).

While such soils can support luxuriant natural vegetation (e.g. rain forest), their cultivation for crops is problematic. Plant nutrients (e.g. Ca, Mg, K, P) are generally lacking. The low pH, coupled with a high levels of iron and aluminium oxides causes phosphorus fertiliser to bind to the soil and become unavailable to plants. Dense natural vegetation can flourish on these soils due to a self-sustaining nutrient cycle. If this cycle is broken (e.g. as a result of deforestation or through the export of agricultural products to urban areas), the soil quickly loses its fertility and is prone to degradation processes such as erosion. Traditional agricultural practices of temporary forest clearance and shifting cultivation recognise this cycle.

Typical Ferralsol from near Jimma, Ethiopia, displaying a characteristic deep, homogeneous, red profile lacking any distinct horizon features. (JD)

• soils with a nitic horizon

In the highlands (>1 000 m) of Ethiopia, Kenya, Congo and Cameroon, a derivation of the ferralisation process can lead to the development of soils containing a characteristic 'nutty', polyhedric, blocky structure with shiny ped faces. Typically, the soil body is deep, developed in fine textured weathering products of intermediate to basic parent material and contains high levels of kaolinite and iron (hence the red colour). In some respects, these soils could be seen as young examples of the ferralisation process. Following the intensive hydrolysis of minerals and leaching of silica and base cations, alternating micro-swelling and shrinking processes produce well-defined structural elements with strong, shiny pressure faces.

The soil body can become highly mixed through biological pedoturbation - the action of termites, ants, worms and other soil fauna – which results in a characteristic crumbly or subangular blocky soil structure and diffuse soil horizon boundaries. The spatial distribution of this process is highly dependent on subtle variations in the landscape and parent material. Soils matching these characteristics are known as Nitisols (see page 55).

A clear example of the typical nut-shaped soil structure from a nitic horizon in Ethiopia. The dark red colour is indicative of a significant amount of clay and active iron. Such soils are associated with the weathering of basic rocks such as basalts. (EM)

• soils with a plinthic (or petroplinthic) horizon

Where the land is level or gently sloping and subjected to fluctuating groundwater levels in iron-rich parent material, a substance known as plinthite can develop (from the Greek *plinthos*, meaning brick). Plinthite, also known in the past as laterite (see box), is a subsurface accumulation of iron(hydr)oxides, kaolinitic clay and quartz. Plinthite is generally formed by the segregation of iron in soil material that has been saturated with water during the year. The iron has probably been transported by soil water from higher ground as ferrous iron under anaerobic conditions. Alternatively, iron concentrations may increase due to the removal of silica and base cations through the leaching of dissolved weathering products. The resulting ferrous iron is precipitated as soft, clayey, red or dark-red ferric iron concretions. Soils matching these characteristics are referred to as Plinthosols (see page 56).

Plinthite cap on the soil surface in Ghana. Plinthosols are formed in low-lying locations where iron-rich water from adjacent uplands can accumulate, precipitate and harden. (EM)

A Petric Plinthosol in lowland position of Sukumaland, near Mwanza, Tanzania. The indurated iron stone cap is clearly evident. This is the place where the Catena concept was developed by G. Milne in 1934 (see page 15). (JD)

When enough iron has been precipitated and the soil starts to dry out, the soft clay begins to harden irreversibly. This is often initiated by removal of the vegetation as this triggers erosion of the surface soil and exposure of plinthite to the open air. Hardened plinthite occurs in concretionary (skeletic) form or as a continuous layer (petroplinthite), also referred to as ironstone. Soils with petroplinthite are especially abundant in the transition zone from rain forest to savannah, especially in areas that were once much wetter.

In other cases the plinthite concretions may not be sufficiently concentrated to form a continuous layer but harden irreversibly as pisolites in a dense layer of nodules. Such layers can sometimes be found close to the surface due to the removal of the soil between the pisolites by termites for building their nests.

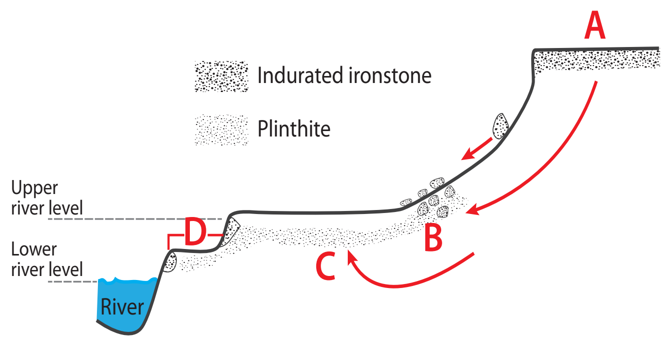


Figure illustrating the four distinct landscape positions where plinthite and ironstone occur. (LJ) [after 24]

A: indurated ironstone (massive iron pan or gravel) capping an old erosion surface. Ironstone caps form a shield against erosion. The result is an inversion of the original relief where parts that initially were the lowest of the landscape become the highest.

B: plinthite and ironstone (gravel and boulders) in a colluvial footslope (subject to iron-rich water seepage)

C: plinthite in soils of a low level plain (river terrace) with periods of high groundwater

D: along the banks of rivers where plinthite becomes exposed and hardens to ironstone

Laterite

The term laterite was developed by British scientists at the beginning of the 19th century to describe the red and creamy mottled clay which was dug out of the ground in India and shaped into bricks. The term was used to describe highly weathered, red subsoils, predominantly under tropical forests, that were rich in iron and/or aluminium oxides, quartz and kaolinite and are nearly devoid of base cations and primary silicates.

Today, the use of the term laterite is discouraged, with preference being given to stricter definitions such as plinthite and petroplinthite.

Acidic or Basic Rocks

The terms acidic and basic are often used to describe rocks or the parent material of soils and does not refer to the pH of the material. In geology, it refers to the amount of silica in proportion to Mg, Fe and Ca.

Magmatic rocks that contain contain significant amounts of silica (at least 66% SiO_2 by mass, which normally occurs as quartz minerals) are referred to as acid. Examples include granite and rhyolite.

Conversely, the term basic is applied to rocks containing minerals such as feldspar and biotite but relatively low amounts of silica. Examples include basalt, dolerite and gabbro. The term mafic is increasingly used in place of basic.

Exposed plinthite may ultimately lead to an inversion of the original relief as it functions as a protective cap against erosion of the underlying soil. Over time, the uncapped soil is removed, leaving the capped soil as the highest parts of the landscape.

• soils with an argic horizon

The climatic conditions in the humid tropics can give rise to a subsurface horizon with a higher clay content than the overlying soil. Such situations can arise as the result of illuviation (see page 25), the destruction of clay in the overlying horizon, the selective erosion of clay, sedimentation or biological activities. Most of the siliceous minerals produced by the original weathering process are subsequently dissolved and leached out of the soil. Depending on the composition of the parent material, clays in the argic horizon can be weathered to liberate large volumes of soluble aluminium. Three common soil types occur in the humid tropics displaying clay-rich subsurface horizons.

- strongly acidic soils that develop on the weathering products of metamorphic rocks containing high-activity clay minerals such as vermiculite or smectite are referred to as Alisols (see page 52). These soils are most common in old land surfaces with a hilly or undulating topography under humid tropical or monsoon climates. The weathering of the clay minerals in the argic horizon gives rise to high levels of aluminium in the subsoil which hinders biological activity.
- strongly acidic soils that develop on the weathering products of acidic parent material (which give rise to an accumulation of low activity clays) in old land surfaces with a hilly or undulating topography under humid tropical climates are referred to as Acrisols (see page 52). Acrisols generally exhibit a strong yellow to red coloured argic horizon overlain by a much lighter (whitish to yellow) bleached horizon.
- where the climate has a pronounced dry season and the soils on old erosional or depositional surfaces are enriched in base cations through different processes (e.g. aeolian dust, biological activity, etc.), the resulting soils are known as Lixisols.

This profile from Ghana contains high levels of aluminium. Such soils occur in the tropics and subtropics, and in the warm temperate regions of the world in relatively young landscapes. The high level of aluminium in these soils is caused by rapid weathering of high-activity clays such as vermiculite and smectite. (EM)

Low and high activity clays

There are two major categories of layered silicate clays within the soil, distinguished on their capacity to retain and supply nutrients such as calcium, magnesium, potassium and ammonium. High activity clays have a cation exchange capacity (CEC) => 24 cmol(+)/kg clay due to their large surface area. Generally, soils with large amounts of high activity clays are not highly weathered and have a high CEC under all pH levels.

In contrast, low activity clays are more highly weathered. Due to their reduced surface area, low activity clays have a lower capacity to retain and supply nutrients (CEC< 24cmol(+)/kg clay) and, depending upon the pH of the soil, supply phosphate, sulphate and nitrate, rather than base cations.

Clay Minerals

Clays form through the weathering of rock fragments, especially those containing a large proportion of silicate minerals. The term 'clay' refers to a naturally occurring particles that are < 2 µm in size and composed primarily of minerals that impart plasticity at appropriate water contents and which harden when dried or fired.

Although the term 'clay mineral' refers to phyllosilicate minerals composed predominantly of silica and aluminium. Aluminium, iron, and manganese oxides (see Glossary) are common components of the clay fraction and play an important role in the chemistry of soils because of their high specific surface areas and reactivity.

Clays are colloidal substances. Their enormous surface-to-surface contact characteristics act as a glue to "stick things together."

Silicate clays have a well-defined, repeating, arrangement of atoms made up of planes of oxygen atoms held together by silicon and aluminium atoms. Thus, the Si^{4+} cation is surrounded by 4 oxygen atoms to form a tetrahedron (4 sided shape). The 6 oxygen atoms needed to fit snugly around the larger Al^{3+} cation form an octahedron (8 sided). The planes of oxygen held together by Si^{4+} cations are referred to as a (silica) tetrahedral sheet.

One plane of oxygen plus a second plane of oxygen atoms (or hydroxyls) held by an Al^{3+} cation are referred to as an (alumina) octahedral sheet. One silica sheet per one alumina sheet is referred to as a 1:1 layer (e.g. kaolinite). With 2 silica sheets per 1 alumina sheet, the lattice is known as a 2:1 type (e.g. illite). In the space between the 2:1 layers, other cations may be present. These cations can be linked with hydroxyls, such as in chlorites. They may also be present as individual cations, which may or may not be hydrated, as in micas, vermiculites and smectites.

A process known as isomorphous substitution occurs when one atom in the crystal lattice is replaced by another of similar size without disrupting the crystal structure of the mineral. In the tetrahedral sheet Al^{3+} usually substitutes Si^{4+}. In the octahedral sheet Fe^{2+}, Fe^{3+}, Mg^{2+}, Ni^{2+}, Zn^{2+} or Cu^{2+} can substitute Al^{3+}. As a result of this process, a net negative charge develops on the clay surface. Clays attract and hold positively charged ions (cations) at their surface. The quantity of cations that can be held, or exchanged, by a given amount of soil is referred to as the cation exchange capacity of that soil. The exchangeable cations are not easily removed by leaching action until they are replaced (exchanged) by other cations. Plants often excrete hydrogen ions (H^+) to the soil solution, which can replace nutrient cations from their exchange sites, thus allowing the nutrients to move to the plant root and be absorbed.

Mineral weathering sequences indicate the likelihood of finding certain clays in various environments. The most resistant products of mineral weathering are those that are the least soluble, such as the iron oxides. During formation, the nature of clay depends on the relative amounts of silica, alumina, iron hydroxides, cations, the pH of the soil solution and the presence of other soluble materials.

Thus, in areas with minimal leaching and minimal weathering, montmorillonite (smectites clays) and vermiculities will form. Some clay minerals are very similar to certain primary minerals (e.g. micas) and may be formed by transformation (slight structural modification).

If the area has more rainfall, relatively more silica will leach away, the pH will be more acidic and kaolinitic clays will form. Under conditions of extensive leaching by rainfall and long-term weathering of minerals in humid, warm climates (e.g. Central Africa), most of the basic cations, silica and some alumina are leached out of the upper soil profile. The remnant materials, which have lower solubilities, are high in alumina and particularly in iron oxides (sesquioxides). Sesquioxides (metal oxides) refer to the clays, which are mixtures of aluminum hydroxide, $Al(OH)_3$, iron oxide, Fe_2O_3, or iron hydroxide, $Fe(OH)_3$. However, TiO_2 and MnO_2 are also often included. These clays can grade from amorphous to crystalline. Iron oxide and iron hydrate commonly colour the soils various shades of red to yellow, respectively.

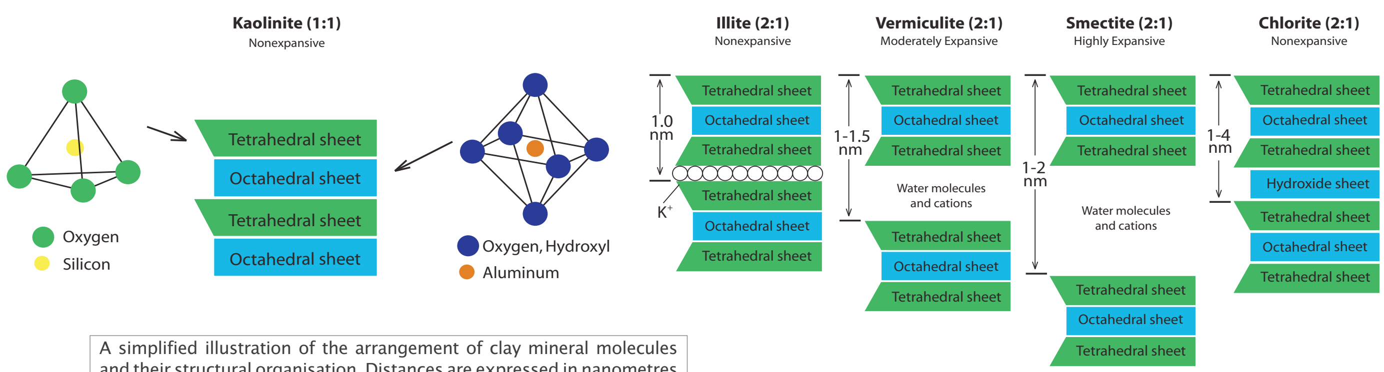
Soil processes on volcanic materials

Soils that develop from ejected volcanic materials such as ash, tuff, pumice, cinders and lava often contain high proportions of volcanic glass. Under a humid tropical climate, intense hydrolysis of the easily weatherable primary minerals and volcanic glass leads to the formation of secondary aluminium- and silica-rich minerals such as allophane and imogolite (under high rainfall) or halloysite (where rainfall is lower). The weathering process liberates aluminium (Al^{3+}) ions, which become tied up with humus in stable Al-organic compounds as the aluminium protects the organic material against bio-degradation. Any free ferric iron (Fe^{3+}) usually precipitates as ferrihydrite (a form of iron oxide).

Such poorly crystalline materials have a large surface area and consequently can absorb large amounts of water. However, due to their high anion exchange capacity (see box left), such materials have a low ability to retain and supply nutrients thus requiring very large additions of phosphorus.

An Andosol that has been buried under a thick basalt flow in the South Ethiopian Rift Valley near Arba Minch. The reddish layer in the centre of the photograph is the baking contact between the old soil and the molten lava. Above this layer, the basalt has solidified and forms the upper part of the cliff. Indeed, the presence of trees on this part denotes that soil-forming processes are active. The pale layer below the baking contact is an old ash deposit from a much older eruption, which was the parent material of the buried Andosol. (JD)

The classic volcanic cone of Ol Doinyo Lengai in Tanzania. In Africa, soils on volcanic deposits are prominent along the Rift Valley (Kenya, Rwanda and Ethiopia), Cameroon, DR Congo and Madagascar. These soils have a high potential for agricultural production but many are not used to their full capacity. By and large, volcanic soils are very fertile, especially on intermediate or basic volcanic ash that is not exposed to excessive leaching. The strong affinity of iron and aluminium (and their oxides) to remove compounds such as phosphorous from the soil solution in a form that makes them unavailable to plants (a process known as sorption) can be a significant problem that requires the application of lime, silica, organic material or phosphate fertiliser. Volcanic soils are easy to till, have good rootability and water storage properties. Landslides and volcanic eruptions are hazards in these areas. (EM)



A simplified illustration of the arrangement of clay mineral molecules and their structural organisation. Distances are expressed in nanometres (nm) which is 1 000 000th of a millimetre – this is very, very small! (LJ)

Soils conditioned by a dry tropical/sub-tropical climate

In the parts of Africa where precipitation is lower than evapotranspiration and high temperatures cause groundwater to rise to the surface, several soil types exhibit substantial secondary accumulations of calcium carbonate (lime), dihydrate calcium sulphate (gypsum) or silicon dioxide (silica).

• soils with accumulations of calcium carbonate

One of the most widespread soil-forming processes in dry climates involves the movement of calcium carbonate ($CaCO_3$) from surface horizons to an accumulation layer at some depth (a process referred to as secondary accumulation). On wetting (such as after rainfall), lime dissolves allowing Ca^{2+} and HCO^{3-} ions to move downwards with the percolating soil water. When the water eventually evaporates, calcium carbonate precipitates where the percolation stopped (calcium carbonate can also percolate if the concentration in solution becomes high enough). Calcite precipitation is not evenly distributed over the soil matrix. Root channels and wormholes act as channels along which the solution can flow allowing the calcite to precipitate on the channel walls. When narrow root channels become filled with calcite, the resulting cast-like shape of the root is known as pseudomycelium. Other characteristic forms of calcium carbonate accumulation are soft or hard lime nodules (calcrete), platy or continuous layers of calcrete and calcite 'beards' known as pendants below pebbles. In eroding land, lime concretions may occur right at the surface of the soil.

• soils with accumulations of gypsum

As **gypsum** ($CaSO_4.2H_2O$) is dissolved from gypsiferous parent materials, it is moved through the soil by water and precipitated in an accumulation layer when the water is removed. Where soil moisture moves predominantly upward (i.e. where a net evaporation surplus exists for an extended period each year), a gypsum-rich horizon occurs within the soil body. Gypsum is also leached from the surface soil in wet winter seasons and re-accumulates deeper in the soil as a loose, powdery substance. Over time, gypsum crystals may cluster together as compact layers or surface crusts that can become tens of centimetres thick. Gypsum can precipitate in former root channels (gypsum pseudomycelium), in voids, as coarse crystalline gypsum sand or in strongly cemented horizons (petrogypsic). In places, it forms massive crystalline structures known as desert roses.

An example of desert rose - the common name given to rosette formations of gypsum with sand inclusions. The rosette shape tends to occur through the formation of crystals during the evaporation of shallow salt lakes in arid sandy conditions. (SH)

• soils with accumulations of silica

In many arid regions (although not exclusively), soils known as **Durisols** contain very hard layers of **silica-enriched** materials in the subsoil. These materials range from silica-cemented sand and gravel to a nebulous matrix enriched with small silica particles. The conditions under which such features develop are uncertain as nearly all occurrences are "fossil" as such soils do not seem to be forming extensively at present. Theories include the precipitation from silica-rich groundwater in arid/semi-arid climates or by intense weathering in a warm, humid climate.

Soils with lower levels of gypsum and calcium carbonate in the upper 30 cm soil layer can support grazing and some drought-tolerant crops when carefully irrigated. The hard duripan material is commonly used for road construction.

A profile of a calcium-rich soil from Tunisia. The white material around the hammer is a dense lime-rich horizon (calcium carbonate). Much of the free lime in the topsoil has been leached out giving it a darker appearance. (TG)

A soil exhibiting secondary accumulation of gypsum from Somalia. The upper part of the profile is almost completely lacking in gypsum, has very low organic matter and a weak, sub-angular blocky structure. Below 40 cm, the gypsum has precipitated along vertical cracks in the soil. (RV)

A duric horizon from South Africa containing rounded or sub-angular durinodes. These indurated accumulations of silicon dioxide are hard and brittle. (EM)

• soils with accumulations of salt

A soil is regarded as saline if the salt concentration is around 2 500 parts per million. Soils affected by soluble salts or by their ions occupy a significant part of Africa. Salt-affected soils are especially prevalent in northern Africa, South Africa, and the less humid parts of central Africa such as northern Cameroon, the Central African Republic, Gabon, Ivory Coast and Liberia.

Soluble salts can be released through the weathering of rocks or because the parent material contains high levels of salt (e.g. old marine sediments or evaporation deposits). However, the majority of salt-affected soils develop where saline groundwater rises to the surface and dissolved salts accumulate in the soil through the evaporation of the groundwater. Salts can also be carried into depressions in the landscape by saline surface water flowing from higher ground. In dry lands, salinity can occur even when the water table is two or three metres from the surface of the soil.

The main ions responsible for salinisation are Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-} and Cl^-. Depending on the chemical composition, the reaction between the soil and salts may differ. Salts containing sodium (Na) cause organic compounds to become mobile and are eventually leached out of the topsoil, resulting in the development of a bleached horizon. The pH of such soil types is typically above 9.

Salts in soil can also occur due to irrigation, since almost all water (even natural rainfall) contains some dissolved salts. When crops use the water, the salts are left behind in the soil and over time accumulate and must be artificially leached out of the root zone by applying additional water. Salination can be increased due to poor drainage or through the use of saline water for irrigating.

Saline soils also occur in ephemeral or closed basin lakebeds, also referred to as salt pans or salt flats. In North Africa, they are referred to as sebkhas, playas, or chotts (e.g. the Chott Djerid in Tunisia).

Salt efflorescence (aluminium and/or iron sulphate) on the surface of a wet, lowland soil near Djiguinoum in Lower Casamance, Senegal. In the past, this area was used for rice cultivation but is now abandoned. (JPM/IRD)

A soil profile from Namibia which has formed by the evaporation of groundwater containing high levels of sodium bicarbonate. The topsoil does not exhibit any well-defined horizons and a salt crust has developed on the surface. (EM)

A close-up of the boundary between the topsoil and subsoil of a sodium-rich subsoil from South Africa. The characteristic columnar structure with rounded tops and the organic coatings on the structural elements are clearly visible. (ISRIC)

• soils in sandy materials

Soils that have developed in coarse material (> 0.063 mm) have poor cohesion and structure coupled with low water retention capacity and organic matter levels. These factors affect soil formation. Large parts of Africa, especially in arid regions are characterised by blown sand (predominantly quartz but other materials, such as gypsum, can dominate). Along desert margins, climatic fluctuations mean that dunes have been fixed by vegetation. In some cases, their aeolian nature is still obvious but in other situations, soil forming processes can give rise to quite different soils (see page 73).

Additionally, soils can develop in the coarse sediments that occur as a result of intense and long-term weathering under tropical climate (see page 28).

A section through a sand dune from Somalia. The soil lacks any structure. There is very little evidence of soil-forming processes. Dune sands display criss-cross bedding that reflect past depositional surfaces (see page 71) . (RV)

What is a salt?

Most people think of salt as the product that they add to food or the substance that makes seawater salty. In most cases, this is the salt sodium chloride (NaCl).

However, salt is the substance formed by the reaction of an acid with a base where the hydrogen of the acid is replaced by a metal ion (some other reactions can also create salts). Hence, sodium hydroxide and hydrochloric acid react to create a salt, sodium chloride, and water. Examples of other salts include copper sulphate, lead nitrate, magnesium chloride and magnesium sulphate.

If solutions of salts are allowed to evaporate, then the salt is precipitated as crystals.

Salts can be clear and transparent or highly coloured and opaque. Different salts can stimulate all five basic tastes. Some salts are odourless while salts of weak acids or weak bases may smell. The solubility of salts depends on their chemistry and the nature of the solvent.

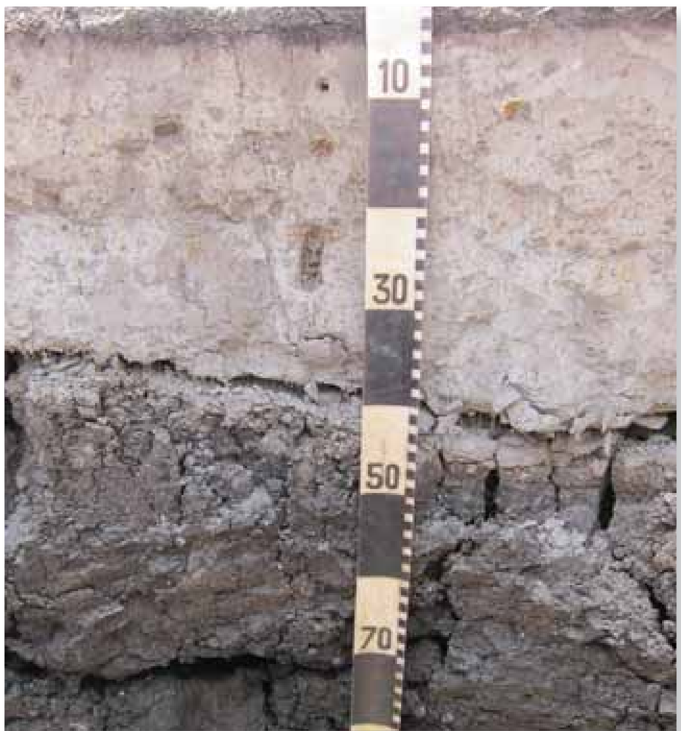
Saline and alkaline soils can seriously affect the growth of plants causing water stress, ion toxicity or the inability to absorb nutrients.

High stocking densities of grazing animals on sandy soils can lead to overgrazing and a reduction in the vegetation cover. Such situations can leave sandy soils vulnerable to wind erosion and, in more arid conditions, more vulnerable to the onset of desertification. The situation can be reversed through effective rangeland restoration practices.

Soils conditioned by water

When it rains, water percolates through the soil and, in many cases, this water drains away. However, in some places the texture of the soil or the presence of an impermeable barrier prevents water from escaping causing pores and cavities to become full of water (also referred to as groundwater). In some soils, groundwater can be found at relatively shallow depths (< 2 m). This situation generally exists due to a slowly permeable substrate, depressions in the landscape which collect water or in marshy areas near to the coast.

The presence of a shallow groundwater table strongly decreases the movement of gases in the soil because oxygen and carbon dioxide diffusion in waterlogged pores is very slow compared to air-filled pores. If organic matter is present in the waterlogged soil, the metabolic activity of the microorganisms will create an oxygen deficit and a state known as 'reduction' develops. In these conditions, ferric iron is converted to the more soluble, and therefore mobile, ferrous iron. While ferric oxides are responsible for giving subsoils their characteristic yellowish- or reddish-brown colours, their disintegration into ferrous oxides will give the soil a distinctive greyish or bluish colour. However, in some of the larger pores where some oxygen may remain, mottles of rust-coloured material indicate the redeposition of ferric oxides. In soil science, two basic types of waterlogged soils are recognised, surface water and groundwater gley.



This soil from Ethiopia is a well developed surface water gley. After rain has fallen, water is held periodically (a state known as stagnant) above an impervious clay-rich horizon (below 40 cm in the photograph). In periods with a precipitation surplus stagnant water can appears on the surface but this will disappear when the soil dries out. This soil is characterised by the presence of grey ped surfaces and root channels while the interior of the peds are enriched by ferric iron. (EVR)

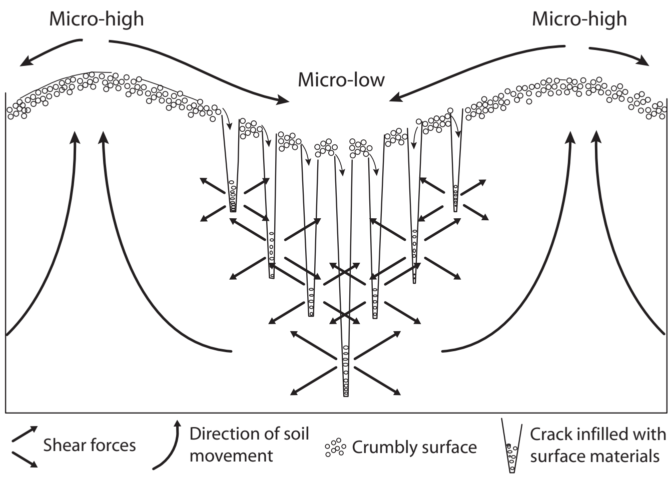
Soils that develop in river (fluvial), lake (lacustrine) and marine (associated with the sea) sediments have a number of distinctive characteristics. The soils of these environments display evidence of stratification (layering) which reflects deposition of the parent material in water. Also these soils are subject to periodic flooding which brings in additional sediments, organic matter and nutrients. Such soils tend to occur on alluvial plains, river fans, valleys and tidal marshes (including mangroves). This picture shows the bank of the Manafwa River in Uganda. The horizontal strata of the fertile loamy sediments are very evident. Changes in colour reflect specific flood events or past soil development. (JD)

Soils conditioned by the presence of swelling clays

In areas with distinct dry and wet seasons and where the parent material contains large quantities of swelling clay minerals known as smectites, soils are characterised by the presence of deep cracks in dry periods which close in the wet season. The closure of the cracks is driven by the expansion of the smectite minerals as they absorb water. Such soils are also defined by the presence of characteristic structural aggregates (spheroids).

Shrinkage of the clay on drying leads to the formation of cracks. In addition, the surface breaks up into granules or crumbs which can fall into the cracks. When the soil is re-wetted, part of the space that the soil requires for its increased volume is now occupied by the granular material in the cracks which results in the build up of shear stress within the soil material. Continued pressures through the uptake of more water eventually cause the soil masses to shear and slide against each other.

The shear planes are known as slickensides and display polished surfaces that are grooved in the direction of shear. Intersecting shear planes produce wedge-shaped angular blocky peds that tend to increase with depth (probably reflecting the moisture gradient). This internal movement of soil, coupled with the deposition of surface crumbs in deep cracks, means that the subsurface soil is pushed towards the surface and mixed. This process is known as churning or pedoturbation. This constant mixing of the soil material results in an extremely deep A horizon. Such soils tend to develop either at the foot of slopes or on plains as a result of the weathering of basalt or redeposition of smectite-rich lacustrine sediments.



A simplified view of the processes operating in soils with swelling clays. During dry periods, the clays shrink causing cracks to open in the soil surface. Over time, crumbs from the surface fall into the cracks. On wetting, clays in the soil body expand causing the cracks close. However, the newly buried surface material causes internal stresses which leads to a mixing of the soil body. This churning often creates a distinctive micro-relief known as gilgai, where the land surface becomes irregular with alternating mounds (puffs) and depressions (hollows). (MF)

Pasture on a soil with swelling clays from the Gonder Region, Ethiopia. The characteristic gilgai microrelief is evident through the dark and light colours of the grass. The darker regions indicate slight depressions. (JD)

Soils with such characteristics are known as Vertisols and are found extensively in Sudan, Ethiopia, Kenya, Cameroon, Chad and parts of South Africa. Vertisols are difficult to cultivate as they can be worked only under a very narrow range of moisture conditions. They are very hard when dry and very sticky when wet. When expanding and contracting, Vertisols can even snap the roots of large plants such as trees.

Soils and the accumulation of soil organic matter

The accumulation and decay of organic matter are critical soil-forming processes. Soil organic matter is derived from the remains and exudes of living organisms (predominantly plants). Organic matter is utilised by a variety of soil microorganisms such as bacteria, fungi and earthworms, as both a source of energy (to function) and materials for building their bodies. During this process, water, carbon dioxide and various organic compounds such as sugars, starches, proteins, carbohydrates, lignins, waxes, resins and organic acids are converted by a process known as mineralisation into inorganic compounds such as ammonium (NH_4^+), phosphate ($H_2PO_4^-$) and sulphate (SO_4^{2-}). This process, together with the release of CO_2 from the soil, is vital for the growth of plants. Some of these compounds are immobilised through being incorporated into the bodies of soil organisms and are only available after the death of the organism.

The annual return of plant and animal residues to the soil varies with the climate, the type of vegetation and how the land is used. Tropical rainforests in West Africa return about 15 tonnes of litter per hectare each year compared to around 8 tonnes for temperate grasslands, 2 tonnes for agricultural soils and 0.1 tonnes for alpine forests. Root decay contributes a further 30-50% of the amount produced from leaf fall.

Peat formation

Peat is a dark, unconsolidated, organic-rich material that has developed when the decay of plant material is repressed as a result of a lack of oxygen in waterlogged conditions (anaerobic) such as those found in bogs, fens, moors, mires or swamps. Three main types of peat are recognised: sapric (very decomposed, hardly any recognisable plant fibres), hemic (moderately decomposed) and fibric (slightly decomposed). Peat accumulates slowly. In Africa, peat deposits occupy relatively small areas: the humid highlands of central and eastern Africa (Burundi, Rwanda, southwestern Uganda, the highland area of the DR Congo, the Aberdane Range and Cherangani Hills in western Kenya), the high-altitude temperate zones of South Africa, Madagascar and the coastal plain of West Africa.

Biko Bog; cool, humid conditions lead to peatland formation at an elevation of 3 400 m in the Ruwenzori Mountains, Uganda. (AJ)

Litter layer on the floor of a tropical rainforest. Rapid decomposition due to high temperatures and humidity levels leads to a dark-coloured surface soil. (OS)

Humus

The decomposition of organic matter leads to the synthesis of new materials, collectively known as humus – a stable, dark brown or black, amorphous material which is less susceptible to decomposition. Humus essentially consists of carbon, oxygen, hydrogen and nitrogen, with organic carbon accounting for 40-60% by weight and is found predominantly in organic-enriched mineral horizons at the soil surface.

Several soil functions are governed by the amount and bio-chemical properties of humus. Humus-rich layers contain considerable nutrient stocks, which are mineralized upon decomposition so that they can be used by plants.

The chemical composition of humus varies and reflects the plants providing the litter, the characteristics of the soil (especially mineralogy and texture) and climate.

Organic v Mineral

Soil material is referred to as organic if it contains more than 20% of organic matter.

Mineral soils by contrast contain less than 20% organic matter but can possess organic surface horizons.

Soils where human activity is a soil-forming factor

Some people argue that all cultivated soils have been affected or altered by human activity through the mixing of topsoil and subsoil by ploughing, changing the chemical balance through liming, or depleting nutrients through intensive farming. However, there are numerous examples throughout Africa where the entire soil body was either totally formed, or at least profoundly modified, through human activities such as the addition of organic materials or household wastes, irrigation or cultivation. Examples include:

- very deep tillage that is below the depth of normal ploughing – often through the use of terraces;
- intensive fertilisation with organic fertilisers such as manure, kitchen refuse, compost, human excrement;
- continuous application of earth (e.g. sods, beach sand, shells) or sediment through irrigation;
- wet cultivation that involves puddling the surface of the soil or human-induced wetness (e.g. paddy fields for rice cultivation).

Another major human management factor is drainage which affects the frequency and duration of periods when the soil is saturated by water. In waterlogged soils, drainage can allow crops to be grown by allowing oxygen to move within the soil. The drainage of peatlands for cultivation can eventually result in total soil loss from shrinkage and wind erosion if the peat is allowed to dry out completely.

While not spatially extensive, soils that have been heavily modified by human activities are very important at a local scale as they characterise private vegetable gardens that are a crucial support mechanism throughout Africa. In this photograph from the Usambara Mountains, Tanzania, farmers prepare wet valley bottom soils for vegetable cultivation by bringing in soil from the uplands as soil improvers. After many years of such practices, the land surface may be raised considerably. (JD)

Soils in very cold conditions

Most people would not associate Africa with very cold conditions, yet the existence of soils affected by freezing and thawing cycles are, curiously, restricted to equatorial central Africa! Mount Kilimanjaro (latitude 4°00' S), Mount Kenya and the Ruwenzori Range, all have peaks above 4 500 m which, coupled with the moist climate, has led to the development of permanent ice fields and glaciers. In this zone, soil water occurs as ice for much of the year. Physical weathering through frost shattering, cryoturbation (mixing of the soil) and the development of patterned ground are present.

Glaciers and permanent ice caps still survive on the summit of Mount Kilimanjaro in Tanzania. At 5 895 m, it is Africa's highest peak. Very cold conditions support cryogenic processes in the soil. However, in such marginal conditions, the permanent ice could soon disappear as a result of global warming and climate change, as has happened on the Virunga Volcanoes of Rwanda and Mount Meru in Tanzania. (WS)

Bokashi – a renewable source of fertiliser in Malawi

In Malawi, agriculture is a key activity, with farmers being challenged to produce more cash crops, such as tobacco, tea, coffee, against a background of increasing resource limitations such as a lack of water, fertilisers and energy. Smallholder farmers, growing such staple crops as maize and vegetables, often cannot afford commercial mineral fertilisers.

One means to address this is to use locally-produced, renewable sources of soil improvement. Several Malawian farmers have been applying a special type of compost known as 'bokashi', made from a mixture of charcoal/ash, maize bran, top soil, dung and water. Also, depending on availability, yeast and sugar can be added. This is mixed and left in the open, ideally taking between 8-14 days to mature depending on the materials used and the weather conditions. Such piles can attract worms, also beneficial to soil structure.

Best made during the rainy season when water is abundant, bokashi is mixed and then dried to form large pellets. Once made, bokashi can be easily stored for later use. Applications of bokashi have been shown to increase crop yields considerably when used alone or to supplement other fertilisers.

Top: A maturing bokashi pile – normally it is allowed to stand for around two weeks. (RBS);
Right: Close up of some bokashi pellets. (RBS)

Biological processes

A section on key soil-forming processes would not be complete without some reference to the role of living organisms. Increasingly, biological activity, especially the activity of insects, is being recognised as an important factor in regulating soil processes and thereby soil profile development – ranging from the physical breakup of bedrock by roots, nutrient cycling and bioturbation, to the bacterial destruction of clay minerals.

In a broad sense, the activity of organisms in the soil is closely linked to climate. Biological activity is virtually absent in hot, dry desert regions. In low temperatures or in very wet conditions bacterial decomposition is reduced and organic matter accumulates. In the warm and wet conditions of the tropics, both bacterial and fungal activity are intense.

In temperate zones burrowing mammals, beetles and earthworms can have a strong influence on soil processes by facilitating the transfer of water and air along burrows and channels. In the tropics, termites and ants play the major role in nutrient recycling and the redistribution of soil material – the movement of particles of subsoil to the surface by termites is one the main factors responsible for the homogenised profiles that are typical of some tropical soils.

As social insects, termites live in colonies that can contain up to several million individuals. In tropical savannahs, termite colonies appear as mounds that can be several metres high and display a complex internal structure. Studies have shown that the orientation of the mounds is related to thermoregulation and the flow of air inside the colony. This is required to sustain the fungal gardens that the termites need to digest their food. The shape of the mound is usually defined by the species of termite in the colony. In the wet semi-deciduous forests of West Africa, termites inhabit dead trees and branches. In these cases, they transport subsoil material into the tree where they paste it on the walls or plug old galleries. Eventually, a mound of soil particles builds up to cover the wood. In time, the wood decays to leave a landscape containing termite mounds which are paradoxically free of termites as they have left the nest before the wood structure collapsed!

This spectacular photograph shows an 8 m section through a termite mound on the border of DR Congo and Zambia. Analytical studies have clearly demonstrated that fungus-growing termites have a great influence on the properties of Ferrasols. Compared to the surrounding soil, termite structures possess a significantly higher pH, higher amounts of 2:1 clay minerals and a much greater capacity to hold nutrient basic cations. (EVR) [26]

Deeply weathered soils in Central Africa

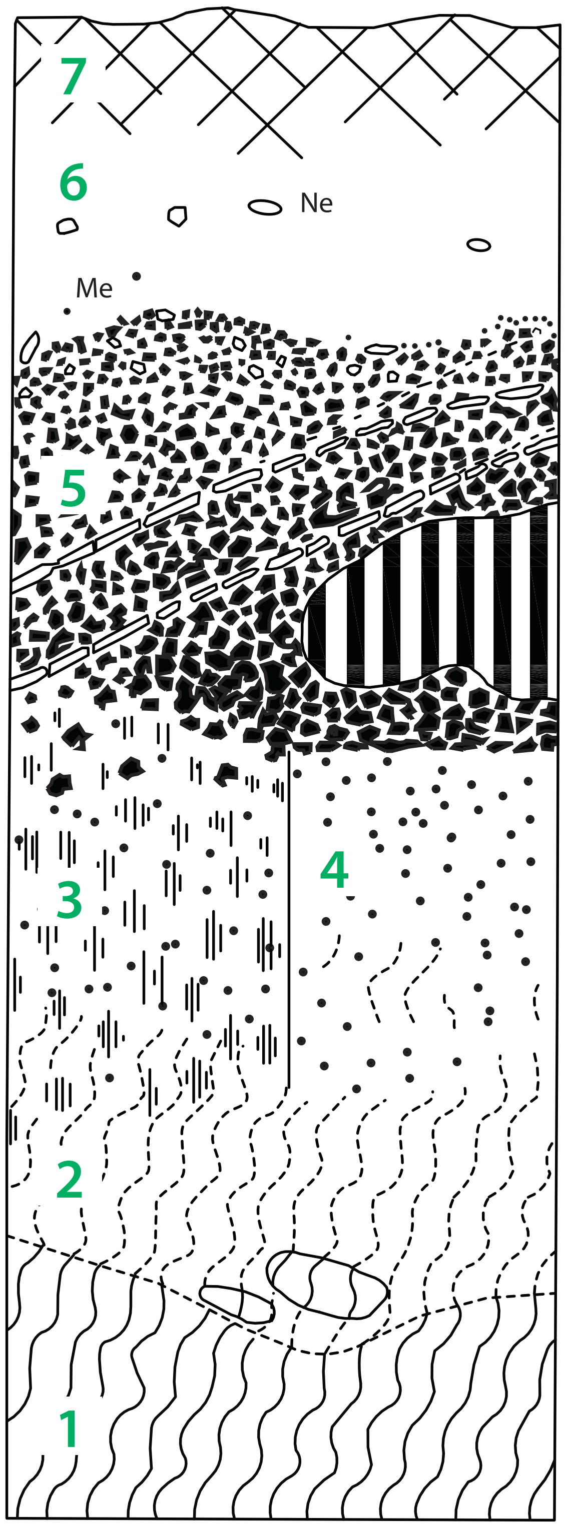
The deep soil profiles that are characteristic of tropical regions are the result of long-term weathering processes, often lasting several million years. Such soils tend to be located on old, tectonically stable plateaus. Chemical weathering under a hot, humid, tropical climate is the dominant process where unstable minerals in the parent material are either dissolved in acidic conditions (carbonates) or decomposed in humid, oxidising environments. Deeply weathered soils also require a moderate relief that allows the leaching of chemically weathered products yet prevents erosion.

Due to their great depth and local variation in the type and intensity of processes, it is difficult to capture all characteristic features of these soils in a single photograph. Therefore, the graphic on the right shows a hypothetical deeply weathered profile.

- The boundary of the weathering front between the parent material {1} and the regolith is characterised by the presence of saprolite {2} or deeply weathered bedrock. It should be noted that on rocks with low silica content (such as limestone, basalt, gabbro, dolerite), this weathered layer is generally absent or very thin.
- If conditions allow, the saprolite can grade into an iron-rich horizon {3} (see page 24) or, if the weathering is very intense, all evidence of the original rock structure (blocks, jointing, veining, etc.) will have been obliterated to form a homogeneous matrix {4}.
- The saprolite layer may be overlain by upper horizons of residual gravels formed from nodules of iron oxide or resistent quartz fragments from the parent material {5}.
- This, in turn, is preserved by residual soils or other sediments deposited over thousands of years {6}. This cover layer may contain stone tools from the Stone Age (which allow the sedimentation to be dated) and is capped by a surface layer containing organic matter {7}.

Truncation of the profile at different depths due to erosion or uplift of the landscape can give rise to a range of different secondary parent materials, hence different soil types. Soils formed in the cover or after slight truncation in the gravel, show ferrallitic characteristics.

Truncation above the saprolite layer results in a parent material suitable for the formation of kaolinitic-rich, highly acidic soils, whereas deeper truncation, reaching the lower saprolite, exposes material where the evidence of soil development is virtually absent.



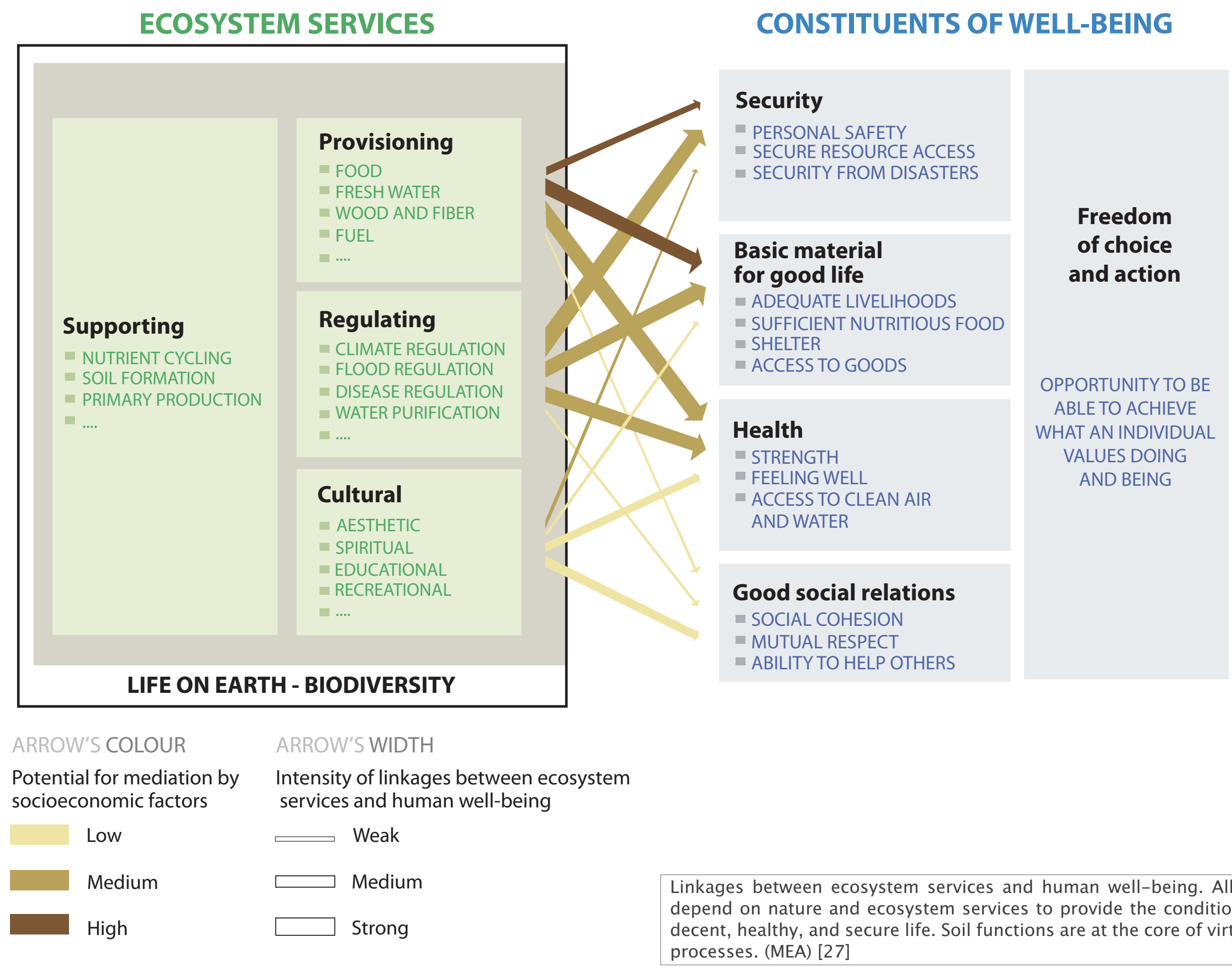
A hypothetical, deeply weathered soil profile from the Congo Basin. (based on GS) [25]

Over many thousands of years, the humid climate of the tropics has lead to the formation of deep and strongly weathered soils. Typical characteristics include the depletion of major elements such as Si, Ca, Mg, K and Na and the relative accumulation of Fe and Al oxides and hydroxides. Cation Exchange Capacity and pH values are generally low, as is the content of soil organic matter. Texture is dominated by sand and clay, with only minor amounts of silt. Soil horizons are often indistinct. (EM)

Key soil functions

While not widely appreciated by most people, soil is actually at the heart of nearly all terrestrial processes on which human and ecological well-being depends. Soil provides, regulates and supports a number of ecosystem services on which issues such as food security, the provision of shelter, access to goods, flood control, combating disease and cultural fulfilment all depend. Soil does all this by performing five essential functions.

- *Growth Medium, Habitat and Biodiversity* - Soil supports the growth of plants and is a habitat for animals and soil microorganisms, usually by providing a diverse physical, chemical, and biological habitat. The provision of food, fibre and fuel from terrestrial crops (including forestry) underpins human societies.
- *Nutrient cycling* - Soil stores, controls the release of, and cycles nutrients and other essential elements. During these biogeochemical processes, analogous to the water cycle, nutrients can be transformed into forms that are easily available to plants, stored in the soil, or even released to air or water.
- *Water cycling* - Soil can regulate the drainage, flow and storage of water and solutes. Soil partitions water for groundwater recharge and for use by plants and soil animals. Soil sealing can destroy this capability, leading to flood events which can kill people and cause untold damage.
- *Filtering and buffering* - Soil acts as a filter that protects the quality of water, air and other resources. Toxic compounds or excess nutrients can be degraded or otherwise made unavailable to plants and animals.
- Support habitation and human health - Soil has the ability to maintain its porous structure to allow passage of air and water, withstand erosive forces, and provide a medium for plant roots. Soils also provide anchoring support for human structures and protect archeological treasures. While a healthy diet is critical to the well being of both animals and humans, soils also support human health as several drugs, for example, antibiotics, were originally synthesised from soil fungi and bacteria.



Linkages between ecosystem services and human well-being. All people depend on nature and ecosystem services to provide the conditions for a decent, healthy, and secure life. Soil functions are at the core of virtually all processes. (MEA) [27]

As for many soil parameters, soil functions are difficult to measure directly, especially over large areas. For these reasons, they are usually assessed by deriving or measuring indicators or proxies that correlate with soil conditions and can be used to assess soil quality and how well the soil is functioning.

Some soil quality indicators are descriptive and can be used in the field (e.g. drainage is rapid) while others are quantitative and must be assessed by laboratory analyses (pH, carbon content). There are three main categories of soil indicators: chemical (e.g. nutritional status), physical (e.g. hydrological characteristics such as water retention by soil structure) and biological (e.g. soil respiration). Organic matter transcends all three indicator categories as it is tied to all soil functions and is itself an indicator of soil quality.

Nutrient cycles

Nutrient cycling refers to the transfer of elements between the soil, vegetation and the atmosphere, which in a natural, balanced ecosystem is self-sustaining and cyclical. The general concepts are illustrated in the adjacent diagram. Most elements have a distinct 'life-cycle' in that they are created by a transformation process and stored in the soil in inorganic or organic forms. If conditions allow, certain elements are then consumed by organisms, which on their death, are returned to the soil so that the process can resume.

Each nutrient has a specific cycle but several elements appear in more than one cycle. Some cycles, such as those of nitrogen, carbon, oxygen and sulphur, involve transfers between the atmosphere, plants and soil while others may only involve movements below ground. The most important parts of the nutrient cycle relate to the exchange of nutrients between three main pools or stores:

Storage in the soil in an inorganic form - during every growing season, plant roots only tap into a small fraction of the soil's inorganic store of P, K, and Ca which is derived from the weathering of minerals, rainfall and dust falling on the surface, the mineralisation of organic matter and the application of inorganic fertilisers. In these cases, the nutrients are made up of ions in the soil solution and exchangeable ions are electrostatically bound to clay minerals and organic matter (see right);

Storage in living organisms below and above the ground – involves nutrients stored in animals, plants and microorganisms. For elements with rapid cycles (e.g. K) the biomass store is very significant. On death, the remnants of living organisms are transferred to the organic pool;

Storage on and in the soil as residues of living organisms - this is the closing loop of the cycle and involves the decomposition of litter, manures and remains of organisms (see page 28).

As a result, there are marked differences in the distribution of elements within the soil. Nutrients that are released at depth by the weathering of minerals are absorbed by plant roots, transported to shoots then deposited on the ground as litter. Inputs from rainfall supplements the surface store. Nitrogen nearly always accumulates in the organic-rich A horizon and then declines gradually with depth. Phosphorus is similar but, due to it's immobility, 90% tends to remain in the top 30 cm of the soil. For potassium, the figure is closer to 50%. Sulphur tends to also accumulate in the surface in temperate environments but in tropical soils, mineralisation and leaching give rise to higher concentrations in the subsoil.

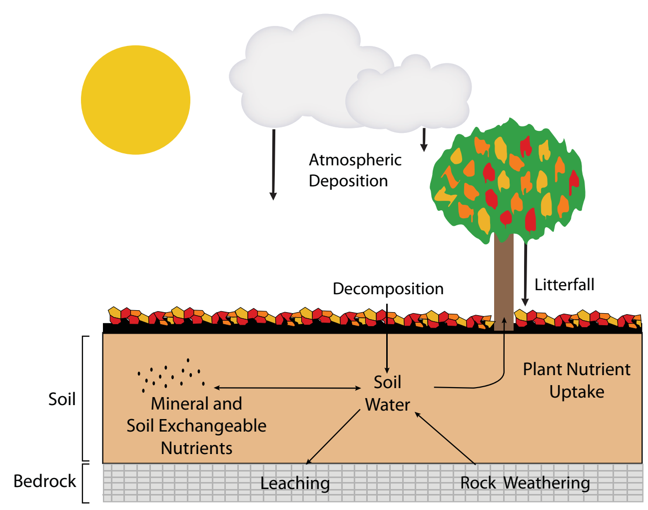
In reality, each cycle represents a balancing act between nutrient inputs and outputs. Inputs can be natural as in the biological fixation of nitrogen or in the form of additions from outside the system (e.g. organic and inorganic fertilisers). Nutrient outputs include a complete removal from the system through crop harvests, wind and water erosion and leaching.

One of the major sources of plant nutrients is soil organic matter which enhances the soil's biological, chemical and physical properties. Plant residues are the main source of soil organic matter while animal manure and urine are secondary sources. In cultivated fields, large quantities of organic inputs must be applied continuously to maintain or improve the level of organic matter. For example, 5 to 10 tonnes/ha of farmyard manure are required to provide a fraction of what would be needed to maintain agricultural production at a desirable level.

However, many current cultivation methods consume many more nutrients than they return to the soil. The situation is particularly evident for the monoculture of cereal crops where almost the entire plant is removed from the soil. For Sub-Saharan Africa, net losses of about 700 kg N, 100 kg P and 450 kg K per hectare have been estimated for around 100 million ha of cultivated land over the past decades [28, 29].

Nutrient depletion contributes directly to a decline in per capita food production in small holdings throughout Africa. Farmers are unable to apply sufficient nutrients due to the high costs of inorganic fertilisers or from a lack of farm machinery. Traditional practices, such as long fallow periods that improve nutrient budgets and restore soil fertility, are difficult to implement due to the increased pressure on land.

Possible solutions involve conservation agriculture which aims to maintain natural nutrient levels through sustainable land management practices or combining organic manures with inorganic inputs. Other sources of organic inputs, such as household organic waste, agro-industrial waste and nutrient-rich sewage and wastewater, could contribute to efficient nutrient cycling but care is needed to avoid contamination of soil and foodstuffs from toxins and pollutants. Finally, a better understanding of the chemical and biological processes that render nutrients available to plants from soil would optimise nutrient cycling and maximise the efficiency of their use.



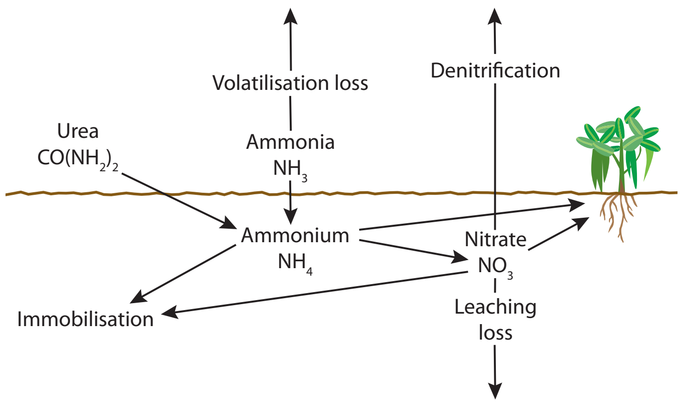
Nutrients in soils may be derived from atmospheric deposition, plant decomposition and mineral weathering. Nutrients are retained by clay particles and organic matter where they can be slowly released into soil water solution for use by plants. However, nutrients may be lost from soils through leaching. (CSS)

The nitrogen cycle

Nitrogen is a critical component of plants. It is a structural component of chlorophyll, nucleic acids (DNA, RNA) and proteins. While abundant in air, nitrogen in the atmosphere cannot be used directly by either plants or animals and must be converted into a usable state. Rainfall often contains substantial quantities of nitrogen in the form of ammonium (NH_4^+) and nitrate (NO_3^-). On contact with the soil, both ammonium and nitrate enter the soil solution easily and are absorbed by plant roots. The microbial decomposition of organic matter results in the mineralisation of organic nitrogen to release the ion NH_4^+ to the soil. Depending on temperature, moisture, the level of soil aeration and presence of some plant species, NH_4^+ is oxidised to NO_3^- , both of which are readily available to plants. Nitrogen may also occur in the soil as the result of mineral weathering, animal urine and through the application of mineral fertilisers (see page 11).

Certain types of bacteria (e.g. Rhizobium) can convert atmospheric nitrogen (N_2) to ammonia (NH_3) through a symbiotic relationship with the root nodules of leguminous plants such as clover (*Trifolium*) or soybean (*Glycine max*). This process is known as nitrogen fixing. Plants convert the ammonia to nitrogen oxides and amino acids that form proteins and other molecules. In return, the plant provides sugars to the bacteria. In order to fix nitrogen, plants such as legumes maintain an oxygen-free (anaerobic) environment near their roots so that the bacteria can exist. Soil pH, organic matter levels and the availability of trace elements such as copper can influence the distribution and activity of these specialised bacteria.

In natural ecosystems, plant growth is relatively slow and the annual uptake of nitrogen is comparatively low (e.g. 30 kg N ha^{-1}). Cultivated crops are much more demanding with nitrogen uptakes that are several orders of magnitude greater (e.g. 500 kg N ha^{-1}). In these cases, the natural nitrogen cycle is unable to maintain optimum growth and artificial inputs must be added to the soil. Harvesting is a critical process as organic matter that would have normally decomposed on the soil surface is often physically removed from the field for processing. This means that there is an export of nitrogen and other elements from the soil to the marketplace. Corrections of N shortages through the addition of mineral fertilisers result in an increase in vegetative growth, much higher protein levels and greater yields of grain and fruit. However, excess amounts of N, above what can be used by plants, are often flushed out of the soil to accumulate in water bodies. Under the right conditions, nitrogen-driven bacterial growth can deplete the oxygen in nearby water bodies to the point that fish and other aquatic organisms die. This process is known as eutrophication.



The principle pathways and transformations of the nitrogen cycle. Nitrogen is important to all life. Nitrogen in the atmosphere or in the soil can go through many complex chemical and biological changes, be combined into living and non-living material, and return back to the soil or air in a continuing cycle. Animals and plants deposit organic nitrogen into the soil. Bacteria convert organic nitrogen to plant-usable ammonium and ammonium to plant-usable nitrates. Denitrification describes the bacterial decomposition of nitrate in the soil to atmospheric nitrogen while volatilization turns urea fertilisers and manures on the soil surface into gases that go directly to the atmosphere (see also page 11). (LJ)

Nutrient depletion in Africa

Several studies have highlighted significant nutrient losses from African soils [28-31]. Models estimate that on average, 660 kg N ha^{-1} have been lost during the past 30 years from about 200 million ha of cultivated land in 37 African countries (excluding South Africa). The FAO estimates that Africa is losing 4.4 million t N every year from cultivated land - these rates are several times higher than Africa's annual fertiliser consumption of 0.8 million t N [28, 32]. N loss is driven by cultivation on nutrient-poor soils, a breakdown of traditional soil-fertility practices and poverty in rural Africa which does not permit effective fertiliser management practices.

The phosphorus cycle

Phosphorus is another vital plant nutrient that forms the backbone of DNA and RNA molecules, forms cell membranes and regulates cell division, root development and protein formation.

Phosphorus deficiency can occur in areas of high rainfall, on acid, clayey or poor calcareous soils. Symptoms include poor growth and leaves that turn blue/green but not yellow. Due to the movement of phosphorus in plants, the oldest leaves are affected first. Fruits are small and taste acidic.

Due to its high reactivity, inorganic phosphorus is never found as a free element, and geologically occurs as phosphate rocks (PO_4^{3-}). In natural ecosystems, phosphorus is released by the decomposition of organic matter as compounds known as orthophosphates (e.g. $H_2PO_4^-$, HPO_4^-). These are rapidly adsorbed by soil particles or immobilised by phosphorus-consuming bacteria (e.g. *Aspergillus*). The pool of phosphorus that is readily available to plants is found in solution or loosely bound on to soil particles.

Because of low concentrations of P in soil solutions and the competition from soil microorganisms, many plants have developed a symbiotic relationships with mycorrhiza – a type of fungus – which in essence extend the root network and provide an improved pathway for the rapid transfer of phosphorus.

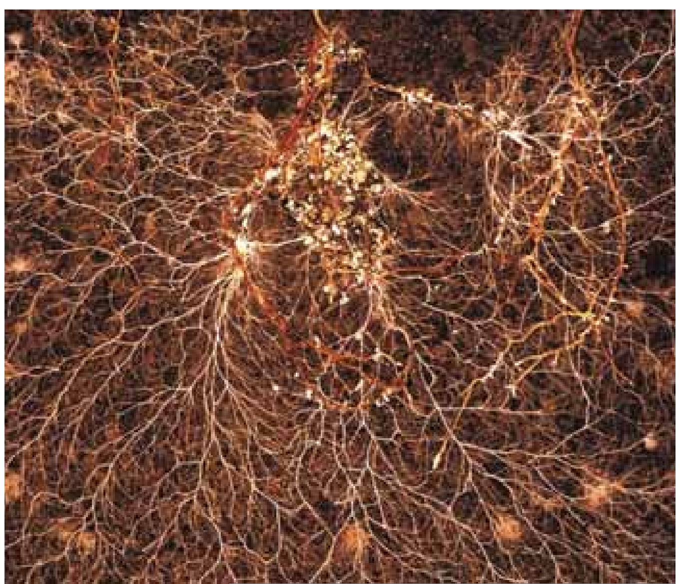
The highly weathered, iron-rich tropical soils of Africa tend to be deficient in plant-available phosphorus. The low pH together with high levels of iron and aluminium oxides, tend to imobilise phosphorus onto soil particles thus denying its availability to plants. In such situations, large quantities of phosphorous fertiliser must be added to the soil to make a difference in crop yields. Lime-rich soils also imobilise phosphorus.

As in the case of nitrogen, it is estimated that around 0.5 million tonnes of phosphorus is lost every year from cultivated soil in Africa - double Africa's annual P consumption [22].

The future of phosphorus?

Due to the essential nature of phosphorus to living organisms, the low solubility of natural phosphorus-containing compounds and the slow natural cycle of phosphorus, the agricultural industry is heavily reliant on fertilisers containing concentrated phosphoric acids (H_3PO_4). About 50% of the global phosphorus reserves are in North Africa and the Middle East. Large deposits of phosphate-bearing apatite exist in China, Russia, Morocco and the USA.

Recent reports have suggested that production of phosphorus may have peaked, leading to the possibility of global shortages by 2040. However, some scientists now believe that a "phosphorus peak" will occur in 30 years and that reserves will be depleted in the next 50 to 100 years. [33]



Photograph taken through a microscope of mycorrhiza (the faint, thin filaments) growing around the roots of a plant (brighter features). Such symbiotic relations can help plants extract phosphorus from soils. (PDI)

The role of soil elements in plant growth

Macronutrients

Macronutrients are elements that are essential to plant growth and are needed in significant amounts. For more details, see [7a].

Potassium (K) is crucial to most plant functions including stomatal control, the maintenance of turgor pressure and charge balance during selective ion uptake across root membranes. It is also an enzyme in many biochemical reactions. Potassium is highly mobile and is easily leached from leaves to be taken up in high quantities by soil microorganisms and roots. In soil, potassium may be found in minerals such as micas and feldspars, secondary aluminium silicates (e.g. illite) and some salts. Potassium is available when attached to clay and humus colloids and easily available when in solution. Potassium dissolved in soil solution as an ion is highly leachable, although loses of potassium from runoff and erosion is not a significant problem.

Calcium (Ca) is used to build cell walls in plants. It helps keep P available in the root zone by binding it with other ions. Because it is bound within cell walls, it does not leach from leaves nor circulate within the plant. Calcium deficiency leads to stunted plant growth, the curling of young leaves and death of terminal buds. Calcium can be easily leached from the soil and is largely absent in the soils of central Africa.

Magnesium (Mg) is the central atom of the chlorophyll molecule and is an important enzyme. It is very mobile in plants. Magnesium deficiency in plants causes yellowing between leaf veins. Low soil pH decreases the availability of magnesium to plants.

Phosphorus (P) is crucial to many plant functions, a key component of most fertilisers, and often lacking in non-fertilised soils. Phosphorus forms the backbone of DNA and RNA molecules and regulates cell division, root development and protein formation (see adjacent text). Phosphorus is responsible for crop yield increases.

The benefits of **nitrogen** (N) are described in the adjacent text.

Micronutrients

Micronutrients are elements that are essential to plant growth but are required in very low concentrations (<100 µg/g). They are generally metabolically active in plants as important enzymes.

Iron (Fe) primarily originates from chemical weathering of minerals and is not absorbed by plants in appreciable quantities; the amount found in plants is several orders of magnitude lower than the amount in the surrounding mineral soil. Iron serves as an electron carrier in enzymes. It also plays a role in nitrogen fixation and chlorophyll formation. Its movements in soil are due to chemical processes rather than an association with organic matter or uptake by plants. The presence of iron oxide gives a reddish tint to soil horizons.

Manganese (Mn) is critical to many plant functions, including photosynthesis, respiration, and nitrogen metabolism. Manganese is generally plentiful in acid soil and may reach toxic levels if pH is below 6.5. It generally leaches out of acidic soils.

Zinc (Zn) is a key component of growth control hormones in plants and is used in protein synthesis. Almost half of the world's cereal crops are deficient in zinc, leading to poor yields while zinc deficiency is the 5th leading risk factor for disease in developing countries. Zinc in soils is tightly bound to magnesium.

Copper (Cu) is especially plentiful in acidic, sandy soils and is an important enzyme activator found mostly in the chloroplasts of leaves.

Toxic elements

Pollutants are contaminants that have been introduced into the natural environment and cause instability, disorder, harm or discomfort to the ecosystem. Artificially high levels of all elements can have harmful or toxic effects. **Aluminium (Al)** is not used in significant amounts by plants. In soils, it immobilises phosphorus and generally increases the acidity and concentration of cations. As for most elements, aluminium becomes toxic to some plants above 1 ppm and to most plants above 15 ppm.

Lead (Pb) binds with organic matter in the soil and accumulates in certain organic tissues of plants. In high enough concentrations, it can cause brain damage in humans.

Other elements that are toxic to plants include arsenic (As), cadmium (Cd), sodium (Na) and even iron (if concentrations are high enough).

Provision of food, fibre and fuel

Perhaps the most readily appreciated soil function is in supporting the growth of agricultural and horticultural crops. The quest for food, fibre for clothing or construction and fuel for heating and cooking has been, and still is for many, of paramount importance to humanity. Soil is the mainstay of agriculture and forestry, forming the physical, chemical and biological medium in which plant growth occurs. Agriculture is the foundation that meets the immediate needs for almost 59% of the African population who live in rural areas and indeed, the soils of Africa do offer great potential for increased agricultural productivity. A staggering 98% of all daily calories consumed in Africa (i.e. kcal/capita/day) come from soil derived products [35].

The most productive soils are those that possess deep, permeable layers, an adequate supply of nutrients, and do not have significant periods of moisture stress. In reality, these correspond to the occurrences of Chernozems, Kastanozems, Phaeozems (temperate grassland soils that are not that widespread in Africa), Vertisols (see page 50 and facing page) and floodplain soils (Fluvisols). Normally these soils are deep with loamy to clayey textures and do not possess impermeable layers. They occur on land that is level to gently undulating, have a balanced nutrient supply and a water-holding capacity of more than 150 mm per metre. Crop yields are generally high and they can support a wide range of agricultural uses.

Agriculture can also be highly successful where seasonal rainfall can support crops, or where appropriate land management practices are needed to overcome some physical constraints. The tropics of Central and West Africa are regarded as having medium agricultural potential due to the presence of acid soils and soils with high phosphate buffering capacity. However, significant specialist assistance and the implementation of appropriate soil management technologies are needed to cultivate these soils.

Woodland and forests cover around 20% of Africa and are important sources of fuel and construction materials. This photograph shows an eucalyptus plantation on Ferralic Arenosols in Congo. Such plantations are replacing natural savannah ecosystems. From this plantation, most of the production, with an average turn-over of seven years, is exported to Europe for paper production. (HDF/IRD)

According to UN statistics, Sub-Saharan Africa (excluding South Africa) is the poorest developing region on the planet, with 29 out of 34 countries being amongst the poorest in the world [34]. With a significant part of the population being low-income farmers and population growth of around 4%, increasing demands on low production land is putting increased stress on soil resources. In parallel, the demand for cereals in Africa rose by around 200% between the early 1980s and 2003 [32].

Poor farmers who cultivate marginal lands face a high probability of crop failure. Adverse climatic conditions (e.g. aridity, drought) and physical soil properties which include surface crusting, impermeable layers, soil acidity, high salinity and alkalinity, wind and water erosion, are all contributing factors, exacerbate by changing climatic patterns.

However, as demand has been rising, there has been an alarming decline in food production in Africa over the past few decades. While there are many political and socio-economic reasons for this situation, major factors have been the decline in the quality of the soil resources and changes in land tenure and agricultural systems (no fallow, commercial production) in many African countries. Fertiliser use in Sub-Saharan Africa is extremely low, averaging at around 9 kg/ha compared to just over 200 kg/ha in industrialised countries, 150 kg/ha in East Asia, and 80 kg/ha in North Africa. This means that large areas of land are cultivated without the addition of fertilisers (generally limited to large commercial farms).

In recent years, the situation has been exacerbated by the rise in price of inorganic nutrients compared to the increase in returns from harvests. Since the 1960s, fertiliser prices paid by farmers have risen by over 600% while income from crops has only risen by half as much. The World Bank noted that between 2006 and 2008, the cost of phosphate fertilisers rose by a staggering 200% making it almost unavailable to farmers in Sub-Saharan Africa who, in order to deal with soil conditions that fix phosphate, need to apply large amounts to guarantee the necessary increase in per capita food production.

Irrigation, terracing and fertilisation of marginal soils can lead to successful crop production systems. This photograph from Ethiopia shows that even steep slopes can be cultivated. However, care is needed to avoid secondary issues such as erosion and contamination of water supplies by fertiliser and pesticide residues. (EVR)

The other major consideration is the loss of food-producing land to alternative uses such as urban and industrial developments, infrastructure projects and the cultivation of high-value or 'cash' crops (such as flowers in Kenya and Ethiopia). The magnitude of these losses are difficult to estimate for Africa as no reliable statistics exist. Cities such as Kampala and Nakuru have grown by 4-15% between 1990 and 2006 (see page 156).

If nutrient levels were to be enhanced and farmers trained in sustainable land management through substantive investment, an estimated 35% of arable land has the potential for sustainable agricultural production. With medium to high levels of nutrient inputs and with the associated services and facilities, the seeds for an African Green Revolution could be sown and Africa's food insecurity could be largely addressed. However, detailed information on the soil resource base is generally inadequate for most developmental purposes and, in most countries, detailed soil maps at farm-level are non-existent. When coupled with other socio-economic constraints such as land ownership, the lack of availability of capital for land management investments and the lack of soil considerations in policy and planning development, the reasons behind the lack of progress in poverty alleviation and food security become clear.

What do we mean by fertile soils?

The previous texts have shown how healthy soils underpin agriculture and that the ecosystem functions that support this are the main nutrient cycles. However, most people are completely unaware of why a particular soil should be more productive than another and how plants access the nutrients that are locked up in the soil. The term 'soil fertility' refers to the inherent capacity of a soil to supply nutrients, minerals, water and air to the roots of plants in adequate amounts. Fertility should be viewed as a natural condition and depends on the main soil-forming factors and soil processes described in the preceding pages. Soil structure and organic matter levels are critical controls of soil health. The concept of productivity could be described as the ability of a soil to produce a crop. Artificial interventions to enhance fertility, such as the addition of fertilisers or drainage, systems, may result in increased productivity or crop yields but at the same time may also upset the natural soil balance (e.g. the rapid depletion of naturally available elements or the increased oxidation of organic matter).

There is a general acceptance that plants require the presence of around fifteen elements in the soil to support healthy growth. These are broadly divided into macronutrients (carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, calcium, magnesium and potassium) which are required in relatively large amounts. Micronutrients or trace elements (iron, zinc, copper, boron, chlorine and molybdenum) are needed in much smaller quantities. This list is not exhaustive as plants also absorb other elements such as manganese, sodium, selenium (have no direct benefit to plants but are essential for healthy animals) and cobalt (critical for the natural fixation of nitrogen by leguminous plants). Carbon, hydrogen and oxygen are generally very abundant and supplied as carbon dioxide (CO_2) and water (H_2O). With the exception of Cl and N, the major source of the other elements is the weathering of parent material and the breakdown of minerals in the soil.

How do plants extract nutrients from the soil?

Plants take nutrients from the soil by a process known as cation exchange which is dependent on soil moisture and sunlight. When plants are photo-synthesising, very fine hairs on their roots pump hydrogen ions (H^+) into water within the soil. These hydrogen ions displace positively charged cations (i.e. nutrients) that are attached to negatively charged soil and organic matter particles. Once these cations are present in the soil water solution, potential energy differences between soil water and roots move nutrients from a higher solute concentration (soil) to a lower solute concentration (plant). Low levels of certain elements can cause symptoms of deficiency in plants, while at a higher level the same element may cause toxicity. Conversely, an abundance of one nutrient may cause a deficiency of another nutrient.

Maintaining soil fertility is an important step in creating sustainable agriculture, food security and economic returns. In natural ecosystems soil nutrients more or less remain stable. However, the harvesting of crops removes some of the nutrients from the cycle thus, over time, depleting the soil. (KH)

Food Security

In recent years, the term 'food security' has been widely used by politicians and decision makers to describe the availability of and access to food [38, 38a]. A society is considered to be food-secure when its citizens do not live in hunger or fear of starvation. The FAO estimates that the number of people without enough food to eat on a regular basis is over 800 million, and increasing. Over 25% of the world's undernourished people live in Africa. In Sub-Saharan Africa, since 2009, over 265 million people are malnourished and 30% of the population suffers from hunger [39]. Many factors influence this situation. Often not enough food is produced or imported to provide a satisfactory base for the diet. At other times, food distribution may be difficult due to poor infrastructure or conflicts. In the first case, efforts to enlarge the food supply are needed.

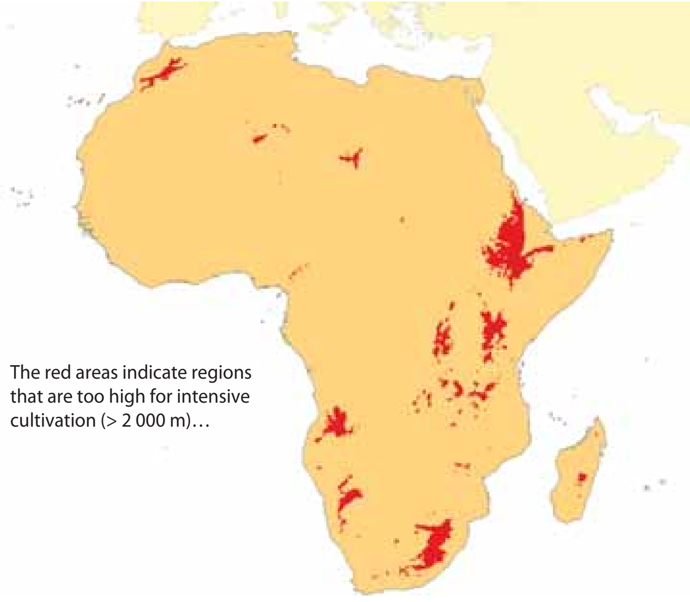
Increasing the productivity of arable soils can be achieved by increasing the number of crops grown each year or by increasing yields. However, both these approaches come with issues. Many parts of Africa suffer from soil nutrient depletion as the components which contribute to fertility are removed and not replaced and the conditions which support soil fertility are not maintained. This leads to poor crop yields. This is exacerbated in the tropics and sub-tropics where the nutrient content of soils is inherently low. Urbanisation and land take often consume productive soils forcing agriculture to move on to less productive, marginal land (most urban areas were originally located on fertile soils in order to ensure food security for their populations).

An additional, but often underestimated, element is food wastage. In 2011, a study produced for the FAO estimated that the total global food loss and waste amounted to one third of the edible parts of food produced for human consumption, amounting to about 1.3 billion tons per year [40]. In industrialised states more than 40% of losses occur at the postharvest and processing stages while in developing countries, more than 40% of losses occur at the retail and consumer levels. The total food waste by consumers in industrialized countries (222 million tons) is almost equal to the entire food production in sub-Saharan Africa (230 million tons) [40].

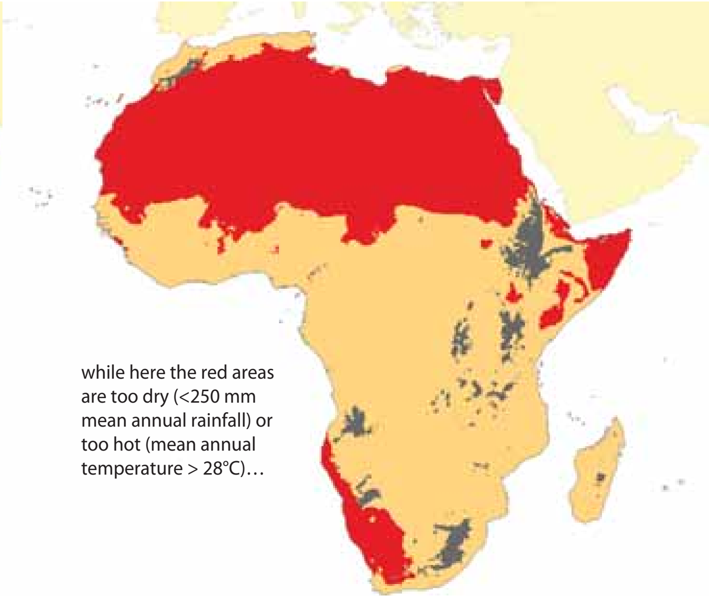
The JRC FOODSEC Action produces regional and annual bulletins each year describing the agricultural and pastoral situation for several African countries.

http://mars.jrc.ec.europa.eu/mars/About-us/FOODSEC/

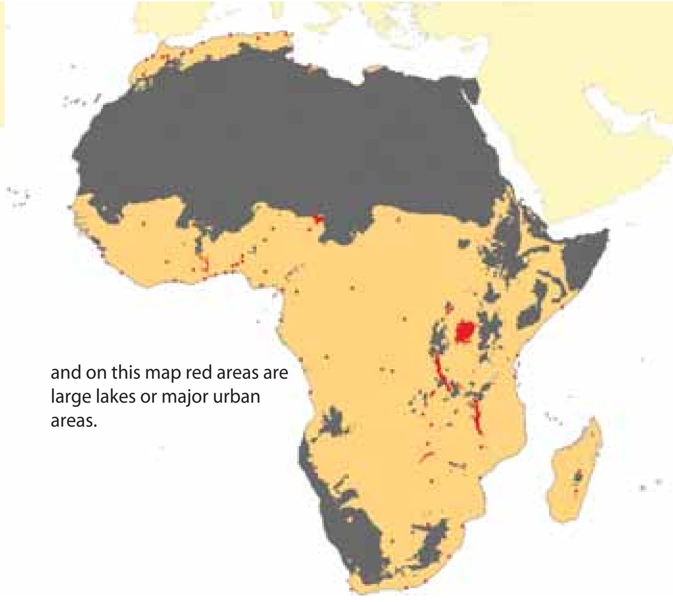
Soil constraints for agriculture in Africa



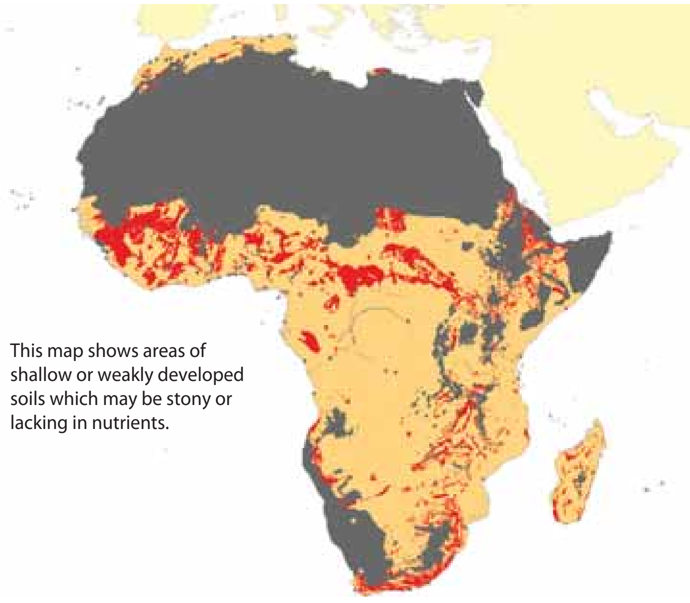
The red areas indicate regions that are too high for intensive cultivation (> 2 000 m)…



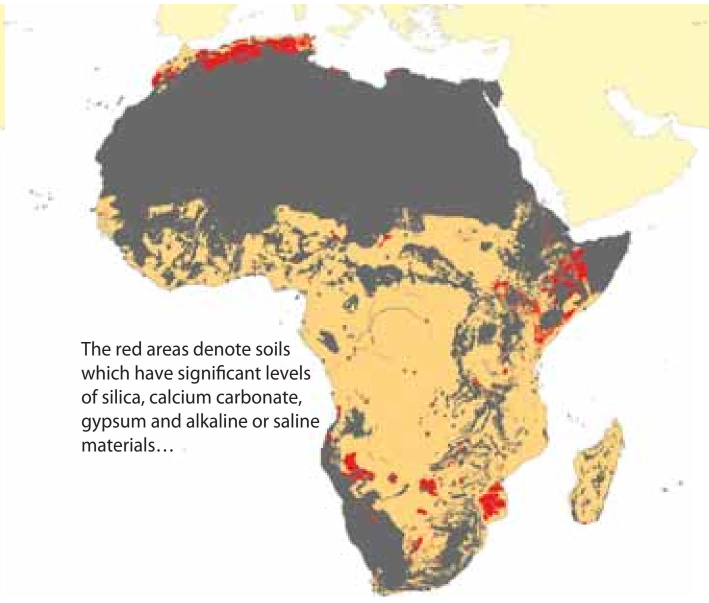
while here the red areas are too dry (<250 mm mean annual rainfall) or too hot (mean annual temperature > 28°C)…



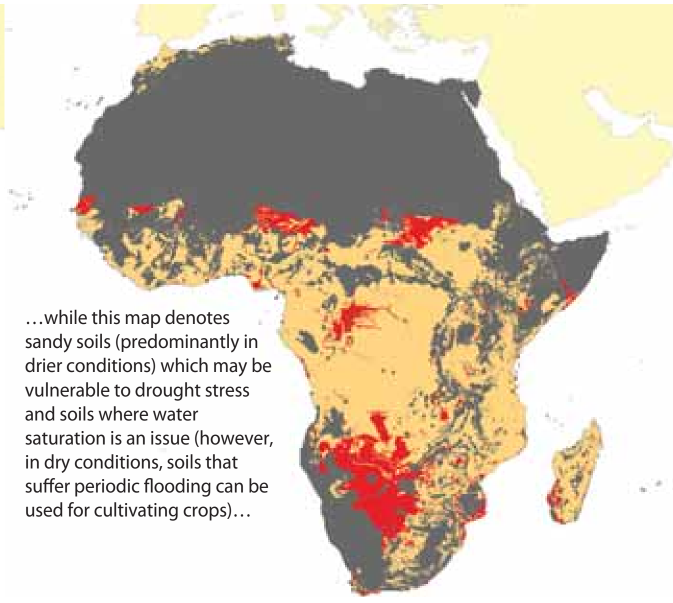
and on this map red areas are large lakes or major urban areas.



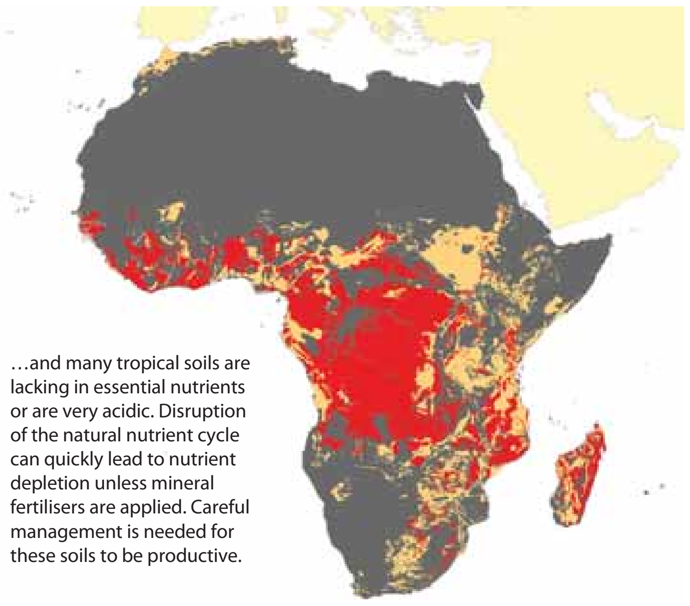
This map shows areas of shallow or weakly developed soils which may be stony or lacking in nutrients.



The red areas denote soils which have significant levels of silica, calcium carbonate, gypsum and alkaline or saline materials…



…while this map denotes sandy soils (predominantly in drier conditions) which may be vulnerable to drought stress and soils where water saturation is an issue (however, in dry conditions, soils that suffer periodic flooding can be used for cultivating crops)…



…and many tropical soils are lacking in essential nutrients or are very acidic. Disruption of the natural nutrient cycle can quickly lead to nutrient depletion unless mineral fertilisers are applied. Careful management is needed for these soils to be productive.

The naturally fertile soils of Africa?

So the soils that remain, the orange areas on the map **below**, covering around 8% of the continent, are relatively free of natural constraints for agriculture. However, this area still includes problematic soils (e.g. waterlogging may restrict some agricultural practices while soils such as Vertisols can be difficult to cultivate when too wet or too dry). It is clear that their distribution across the continent is uneven with large expanses seemly devoid of fertile soils! It should be stressed that the maps on this page present a very generalised view - human activity can have a positive impact on soil quality by allowing crops to be grown where conditions are not optimal, especially at local scales (see box below-left).

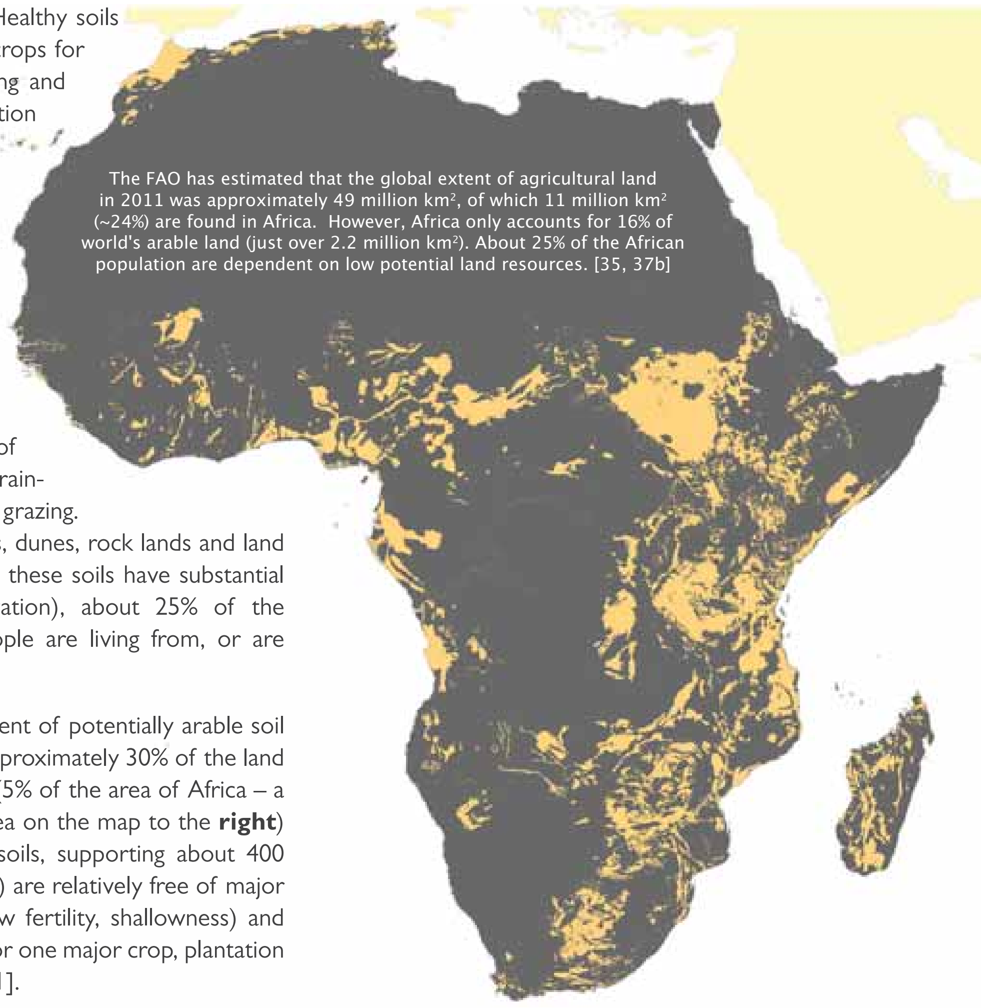
Soil is at the heart of food security. Healthy soils are needed to sustain life – to grow crops for food, feed for animals, fuel for heating and cooking and materials for construction and utensils.

Unfortunately, the conditions required for naturally fertile soils mean that the distribution of such land is limited across Africa. This page illustrates the environmental constraints to agricultural production.

Fifty-five percent of the surface area of Africa is unsuitable for any kind of rain-fed agriculture other than nomadic grazing. These are largely the deserts, salt flats, dunes, rock lands and land that is too steep to cultivate. Though these soils have substantial agricultural potential (e.g. with irrigation), about 25% of the population or about 250 million people are living from, or are dependent on, these resources.

The USDA has estimated that the extent of potentially arable soil in Africa is around 9 million km² (or approximately 30% of the land mass) of which 16% is of high quality (5% of the area of Africa – a value surprisingly similar to orange area on the map to the **right**) and 13% of medium quality. These soils, supporting about 400 million people (40% of the population) are relatively free of major soil constraints to agriculture (e.g. low fertility, shallowness) and rainfall is usually stable and adequate for one major crop, plantation agriculture, forests and aquaculture [41].

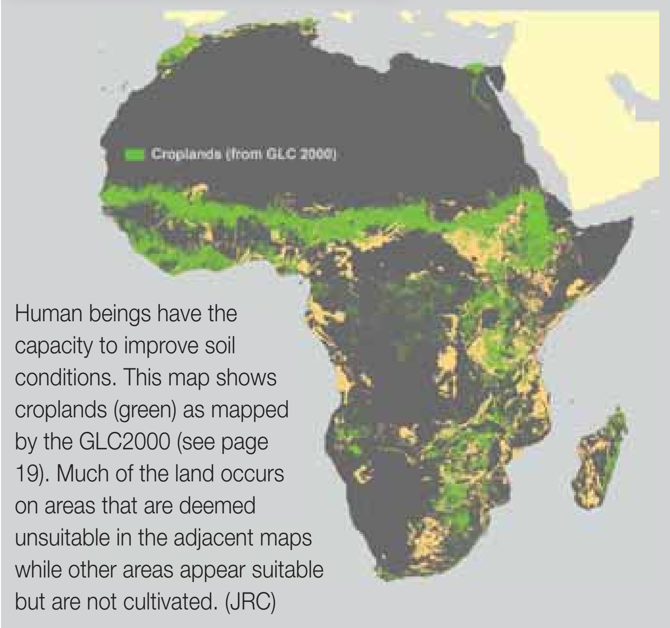
Sustainable management and effective conservation practices are essential to maintain soil fertility and thus ensure secure food supplies and reduce global poverty [37, 37a, 37b].



The FAO has estimated that the global extent of agricultural land in 2011 was approximately 49 million km², of which 11 million km² (~24%) are found in Africa. However, Africa only accounts for 16% of world's arable land (just over 2.2 million km²). About 25% of the African population are dependent on low potential land resources. [35, 37b]

Maps based on data from the FAO Map of World Soil Resources 1:25 000 000 [23], WorldClim climate and elevation variables [12] and the Global Land Cover Map 2000 [16a].
Maps elaborated by JRC.

The human touch?



Human beings have the capacity to improve soil conditions. This map shows croplands (green) as mapped by the GLC2000 (see page 19). Much of the land occurs on areas that are deemed unsuitable in the adjacent maps while other areas appear suitable but are not cultivated. (JRC)

Traditional soil use and agriculture

Threats to shallots cultivation in southeast Ghana

Close to the estuary of the River Volta, one can find an extraordinary, intensive horticulture system on beach sands. Despite its semi-arid climate, farmers on the Keta sand spit in southeast Ghana have developed a sustainable horticultural production system based on shallot cultivation on soils which have low nutrient content, low water holding capacity and a climate with a long dry period! However, the input of new technologies are threatening the very existence of this fragile system.

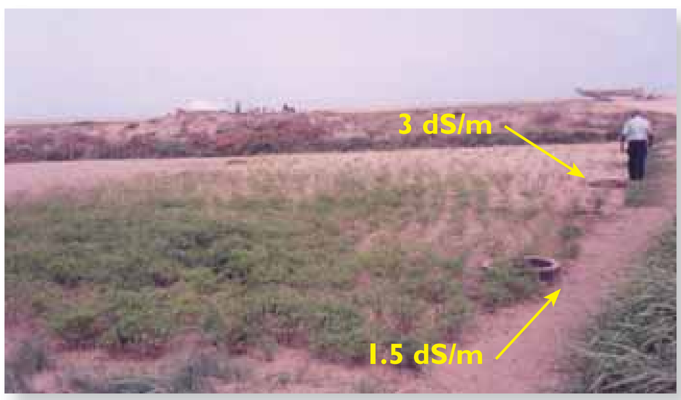
Shallot cultivation is a cash crop which is highly dependent on a substantial input of organic matter (manure) and water. Three growing seasons are supported. Traditionally, organic matter inputs came from poultry manure, fish remains and wood ash. The first growing season is totally rain-fed, the second is partly rain-fed while the last one, in the dry season, is totally dependent on irrigation water extracted manually from wells dung into a shallow aquifer held in the sand. Yields decrease with each cultivation (30% reduction between the first and the last) probably due to a slight increase in soil salinity as a result of the irrigation water. This system has been maintained for more than 100 years and has provided a stable income for local farmers.

Recently, the introduction of electric pumping systems have made sprinkler irrigation possible and allowed a larger area of the sand spit to be cultivated. However, this development is a severe threat to the sustainability of the farming system. The increased consumption of water appears to be greater than the recharge of the freshwater lens which, if not managed correctly, could become depleted and be replaced by salt water intrusion from the adjacent sea.

Due to the already marginal conditions, competition with other shallot-growing areas is intense and profit margins are low. Some farmers are already making a transition to a pepper-okra-tomato cultivation system which gives higher prices but requires more inputs of manure and water. Cow dung manure is now being transported to the area from a distance of around 100 km. However, the cow manure has led to weed infestations which need to be treated with herbicides. Given the porous nature of the sandy soil, there is a high risk of groundwater contamination from plant protection products. As a consequence, quotas on water extraction and limits on the use of manure may undermine the change of farming system nor is it certain whether it can even survive in its present form.

Above: Traditional agricultural methods which took note of local soil and climatic conditions in southeastern Ghana supported a sustainable farming system despite the low nutrient content and poor water holding capacity of the soils. (HBM)

Below: A dramatic example of the influence of salt on crop development. Salt levels in the well in the foreground are half those of the adjacent well. Crops irrigated with saline water (in the background) display less growth. (HBM)



Traditional techniques for the rehabilitation of degraded soils in the Sahel

The combined effects of climatic conditions, inherent poor soil quality and human activities have resulted in severe soil degradation across the Sahel. Soils display well-developed crusts while erosion by water and wind is substantial. Cultivated lands are particularly characterised by a gradual loss of structure, hardpan formation, reduced permeability, compaction and inadequate aeration which limit root development. Such soils are known as zipellé in Burkina Faso or hardé in Chad. Typical characteristics are shallow depth (< 50 cm), a pH of around 5, soil organic mater content of 1.2%, N < 0.6 g kg^{-1} and very low in nutrients (CEC is 0.11 cmol^{+} kg^{-1}). However, the reintroduction of two traditional soil management practices has shown great potential to combat land degradation while improving the productivity of sealed and crusted bare soils, previously abandoned as wasteland.

The zai method (also called tassa in Niger or towalen in Mali), is a soil rehabilitation system that concentrates runoff water and organic matter in small pits (20-40 cm in diameter and 10-15 cm deep) dug manually during the dry season. A handful of animal manure or compost is added to each pit.

A young sorghum crop growing in Zai pits in Burkina Faso. (RZ)

The second method, originating from Niger, is the half-moon. This consists of a basin 2 m in diameter, dug with a hoe or a pick in order to break the crusted layer on the soil surface and to collect runoff water. The cultivated area for each half-moon is around 6 m^2. A barrowful (35 kg) of animal manure or compost is supplied to each half-moon.

Rain and runoff water collects in half-moon basins. Stone boundaries across the slope reduce runoff rates. (RZ)

Both practices are efficient in improving soil productivity. The application of organic matter enhances soil nutrient levels and improves crop nutrient uptake from soil reserves. The manure also attracts termites which improve soil structure through their nesting and foraging activities. This change in structure, together with the digging of the pit and breaking the crust, leads to increased water infiltration and drainage, lower runoff and reduced resistance to root penetration. The improved water status in the soil, increased decomposition of organic matter and nutrient release, result in substantial gains in sorghum grain yields of around 700-1 500 kg ha^{-1} compared to yield rates of 100 kg ha^{-1} in soils without any intervention.

Additionally, seeds included in the manure allow for the regeneration of shrubs and trees. Several studies have reported the re-establishment of herbaceous and woody species on formerly bare soil following two consecutive years of zaï in the central part of Burkina Faso (see page 148).

The Chagga Gardens: sustainable use of soils of the southern slopes of the Kilimanjaro

The Chagga people are the third largest ethnic group in Tanzania. They live on the southern and eastern slopes of Mount Kilimanjaro (and Mount Meru, as well as in the Moshi area) at an altitude of between 900 m and 1 900 m. The favourable climate, fertile volcanic soils and sustainable agricultural practices have supported the Chagga for thousands of years.

The Chagga are exponents of a practice known as forest gardening, a low-maintenance organic plant-based food production and agroforestry system. Forest gardening is believed to be the oldest form of land use in the world and is a great example of the benefits of poly-cultivation (i.e. the opposite of monoculture). Fruit and nut trees, shrubs, vines, herbs and perennial vegetables are inter-planted to give a multi-layered cropping system that replicates a woodland habitat. Root vegetables such as yams and sweet potatoes are grown in the soil, interspersed with eggplants, beans and maize. Coffee bushes provide a cash crop while banana and nut trees ensure a staple food source. Plant species (e.g. *Datura arborea*, *Rauwolfia caffra*) are grown to repel or eradicate various pests.

The sloping ground of Kilimanjaro is terraced to enable deep cultivation and reduce soil loss due to erosion. Manure from oxen and bird droppings are added to the soil as organic matter inputs. Each garden has a network of irrigation and drainage furrows allowing farmers to use runoff from the forest and other home gardens on higher slopes during dry periods.

Forest gardening is widespread in rural, suburban and urban areas of many African countries, particularly Malawi, Tanzania, Zambia and Zimbabwe. Such approaches play an essential role in establishing food security as most of the produce is used for subsistence. Women are usually the main actors in this system.

Continuous vegetation cover, fast growing nitrogen-fixing plants and inputs of compost and animal manure ensure that this Nitisol in the Chagga Gardens of Tanzania remains fertile. The high clay content of the soil is very evident below 20 cm (0–20 cm has been mixed by cultivation). (EM)

Banana trees interspersed with coffee bushes on the slopes of Kilimanjaro in northern Tanzania. Unlike other species, *Coffea arabica* prefers light shade which makes it ideal for forest gardening systems. Most of the coffee produced by the Chagga is exported to Europe. (EM)

Soil carbon cycle

The biological carbon cycle

One of the most important functions of soil is its role in the terrestrial carbon (C) cycle by facilitating the conversion of atmospheric carbon dioxide (CO_2) to living matter and then its breakdown and release to the environment. Biology plays an important role in the movement of carbon between the soil and atmosphere. Through photosynthesis, green plants use solar energy and water to turn atmospheric CO_2 into carbohydrates (i.e. sugars, starch and cellulose), the principle compounds that are necessary to build up biomass for plants or the bodies of animals. Most carbon leaves the biosphere through respiration and the decomposition of organic matter ($C_6H_{12}O_6$, e.g. litter fall, roots). Where oxygen (O_2) is present, aerobic respiration occurs, which frees the energy contained in the sugars and transforms carbohydrate 'fuel' back into carbon dioxide, which is released back to the atmosphere as follows:

$$C_6H_{12}O_6 + 6O_2 \text{ ---> } 6H_2O + 6CO_2 + \text{energy}$$

When oxygen is lacking, for example in soil that is saturated with water due to poor drainage, then microbial communities (e.g. Methanobacterium, Methanosaeta and Methanosarcina) catalyse the breakdown of organic matter (anaerobically). In these conditions, organic matter is broken down to produce methane (CH_4) and carbon dioxide:

$$C_6H_{12}O_6 \text{ --->} 3CH_4 + 3CO_2$$

The amount of carbon entering the terrestrial carbon cycle by photosynthesis and released back into the atmosphere by respiration each year is about 1 000 times greater than the amount of carbon that moves through the geological cycle on an annual basis. Carbon dioxide and methane are important greenhouse gases that affect the Earth's climate. This makes soil an important component in the study of climate change.

Soil organic matter and carbon

Organic matter is often described as the 'life-force' of the soil. It creates pores in the soil which help the roots of plants to develop and stores significant amounts of water thus increasing the soil's capacity to withstand drought conditions. Organic matter can attract the ions of essential nutrients and, as a result, reduce the risk of valuable plant food being leached away. The same process can occur with certain pollutants which limits the potential contamination of soil and groundwater. Finally, the biochemical structure of organic matter can help to buffer excessive acid or alkaline soil conditions.

The amount of soil organic matter is determined by a balance between biological inputs (e.g. plant residues), the rate of humus formation and its loss, which comprises decomposition of vegetation and humus mineralisation. Depending on the climate and land use, organic matter can remain stable in soil for long periods. However, the level of organic matter in soil can be manipulated through variations in input or output conditions. Several land management practices, such as the harvesting of crops or drainage, remove carbon from the soil. Minimal or no-till cultivation, mulching crop residues, crop rotation, and inter-cropping with perennials all enhance the formation and increased storage of organic matter in the soil. The drainage of peatlands leads to significant losses of organic matter and emissions of CO_2 to the atmosphere and should be avoided.

It is generally accepted that most soil organic matter contains between 40 to 60% C (by dry weight).

Soil organic carbon and soil functions

Low levels of organic carbon in the soil are generally detrimental to soil fertility and water retention capacity, and tend to increase vulnerability to soil compaction, which leads to increases in surface water run-off and erosion. Other effects of low organic carbon levels are a reduction in biodiversity and an increased susceptibility to acidification. Climatic conditions strongly influence both the trends and rates of accumulation and transformation of organic substances in the soil.

Soil organic carbon and soil functions

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Measuring carbon in soil

Although there are some promising new technologies, soil carbon usually cannot be measured directly in the field. Samples must be collected (see below) and sent to a laboratory for analysis. The most accurate method for measuring soil carbon is through dry combustion in an elemental analyser. These instruments heat a very small sample of dry pulverised soil to around 1 000°C and then measure the CO_2 levels that are released through the combustion process. If the sample contains carbonates or inorganic carbon, then the soil is pre-treated with hydrochloric acid to remove the inorganic compounds. Results are expressed as the percentage of carbon in the sample.

Traditional procedures for determing soil organic carbon are the loss on ignition (LOI) and Walkley-Black tests. However, both are less accurate than the elemental analyser process described above. LOI measures the loss of weight of organic matter in a dry soil sample after it has been heated in an oven to around 400°C for a few hours. The Walkley-Black method uses potassium dichromate to liberate the carbon in a sample. As both of these tests only measure organic carbon, neither can extract all the carbon that is present in a soil sample.

Calculating soil carbon stocks

The amount (or stock - t ha^{-1}) of soil organic carbon (SOC) can be calculated to a given depth using the following equation [45a]:

$$SOC = C * BD * T * (1\text{-}VS/100) * T*10^2, \text{ where:}$$

- C is the organic carbon content for a specific soil type (% weight) for a given depth - determined by laboratory analysis;
- BD is the soil bulk density (g cm^{-3}) - a crucial factor which describes the weight of an undisturbed soil sample. Bulk density can range from 0.1 for light peats to 1.8 for very dense, compacted mineral soils;
- VS is the volume of coarse fragments (and/or ice) in the soil (% volume)a measurement recorded in the field;
- T is the thickness of the soil layer (e.g. 0.30 m).

SOC is normally expressed in tonnes of carbon (tC), gigatonnes (Gt = 1 billion tonnes) or peta-grammes (Pg = 1 0^{15} g).

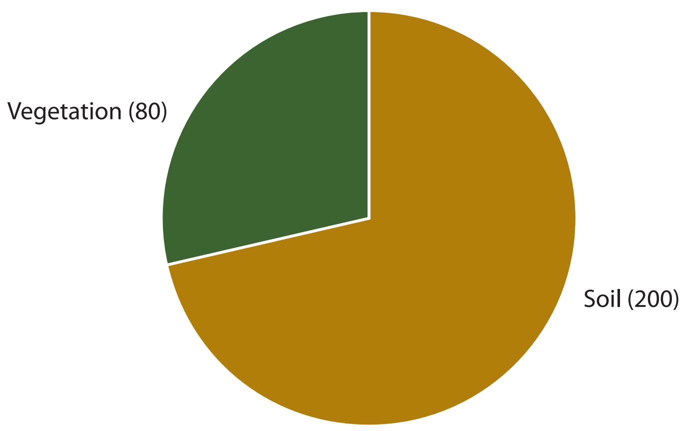
Problems in measuring carbon in soil

While the carbon content for a specific location can be calculated accurately using the methodology described above, the result is only applicable to the sampling location. The inherent variability of soil across the landscape means that the soil characteristics may be quite different a few metres away from a sampling site which means that the carbon content may also be different. Soil scientists often take several samples within a soil body to determine an average or 'typical' carbon content or density for a particular soil type.

Organic carbon in African soils

One of the most striking features of African soils is the huge range in values and the diversity in the distribution of soil organic carbon (see map on page 39). Values ranging from very low or negligible levels in the deserts of the Sahara, the Kalahari and the Horn of Africa to very high in the wetlands of Sudan (Sudd), DR Congo (Ngiri-Tumba-Maingombe), Congo (Sangha-Nouabalé-Ndoki), Rwanda, Burundi, Tanzania and the Barotse Flood Plain in Zambia [42-43]. The soils of the tropical zone contain slightly more carbon than the soils of the savannah regions.

The impact of land use change on carbon varies depending on type of change. The conversion of tropical forests into farmland reduces topsoil carbon content by 20 to 50% of the original levels through reduced production of detritus, increased erosion rates and increased decomposition of soil organic matter by oxidation. Deeper layers tend to be less affected. The conversion of forests to pasture appears not to change soil carbon dramatically and may even increase levels in some cases but may affect other issues (e.g. biodiversity, erosion). [44-45]

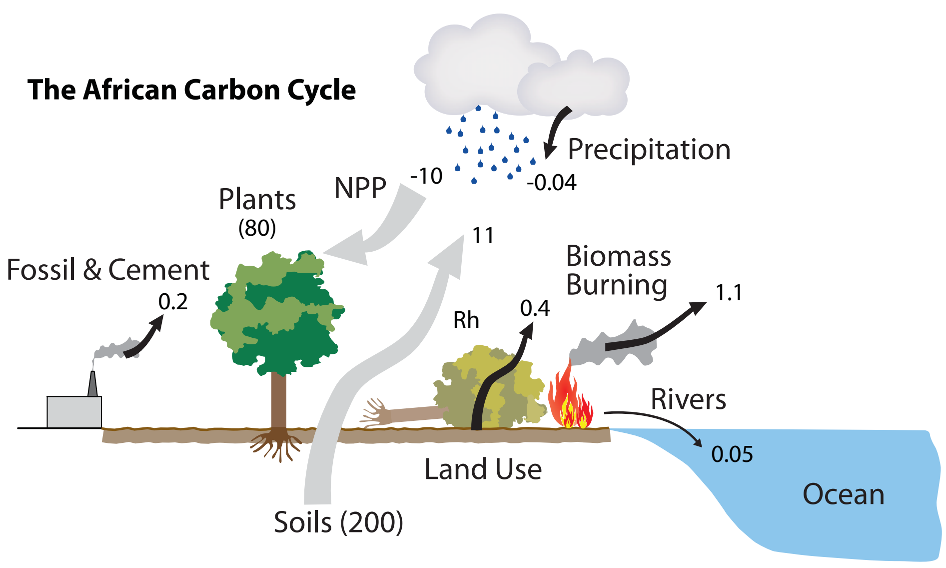


While exact figures do not exist, most studies indicate that the soils of Africa store about 2.5 times the amount of carbon contained in above-ground vegetation (values in 10^{15} g C). (JRC) [based on 43]

Global carbon balances

The largest global carbon reservoir is the deep ocean which contains close to 38 000 Gt C compared to around 2 200 Gt C on land, 750 Gt C in the atmosphere and 1 020 Gt C in the upper ocean (1 Gt is one billion tonnes).

Of the land pool, an estimated 1 600 Gt C are stored in the soil while vegetation holds around 500 Gt C.



A schematic representation of the African carbon cycle showing the main stores of carbon and the fluxes (exchanges) between them. The importance of the soil carbon reservoir is clearly apparent. In general terms, Africa emits slightly more carbon on an annual basis than it sequesters. Soil is by far the largest store, holding an estimated 200 Gt of carbon, with vegetation accounting for around 80 Gt C. With 11 Gt C, soils are also the largest emitter of C in Africa, primarily due to microbial or heterotrophic respiration (Rh) and decomposition of organic matter. However, this amount is almost offset by plant productivity (net primary productivity - NPP). On the other hand, carbon emissions due to land clearance and the burning of biomass are markedly higher than emissions due to the combustion of fossil fuels (e.g. oil and gas). While they affect large areas, emissions from savannah fires are offset by the subsequent regrowth.

While current data suggest only a small carbon imbalance across Africa, climatic fluctuations (especially drought) can lead to sizeable changes in net ecosystem productivity and increases in wildfires. In these situations, the land system of Africa becomes a major source of global carbon emissions.

Considering the current and increasing pressures on land across Africa (climate variability, land use change, population growth, industrialisation and urbanisation), carbon emissions are likely to undergo substantial changes over the coming years. (based on CW) [43]

All units are 10^{15} g of carbon.

Soil organic carbon in Africa: a perspective

Soil carbon and soil type

It is clear from the earlier text on soil-forming factors and soil processes that organic carbon content will vary according to the type of soil. Histosols in Africa (by definition soils rich in organic matter – see page 54) can contain close to 100 kg C m^{-2}, while Gypsisols (a desert soil containing high levels of gypsum and found only in very arid climates – see page 54) typically contain only around 1 kg C m^{-2}.

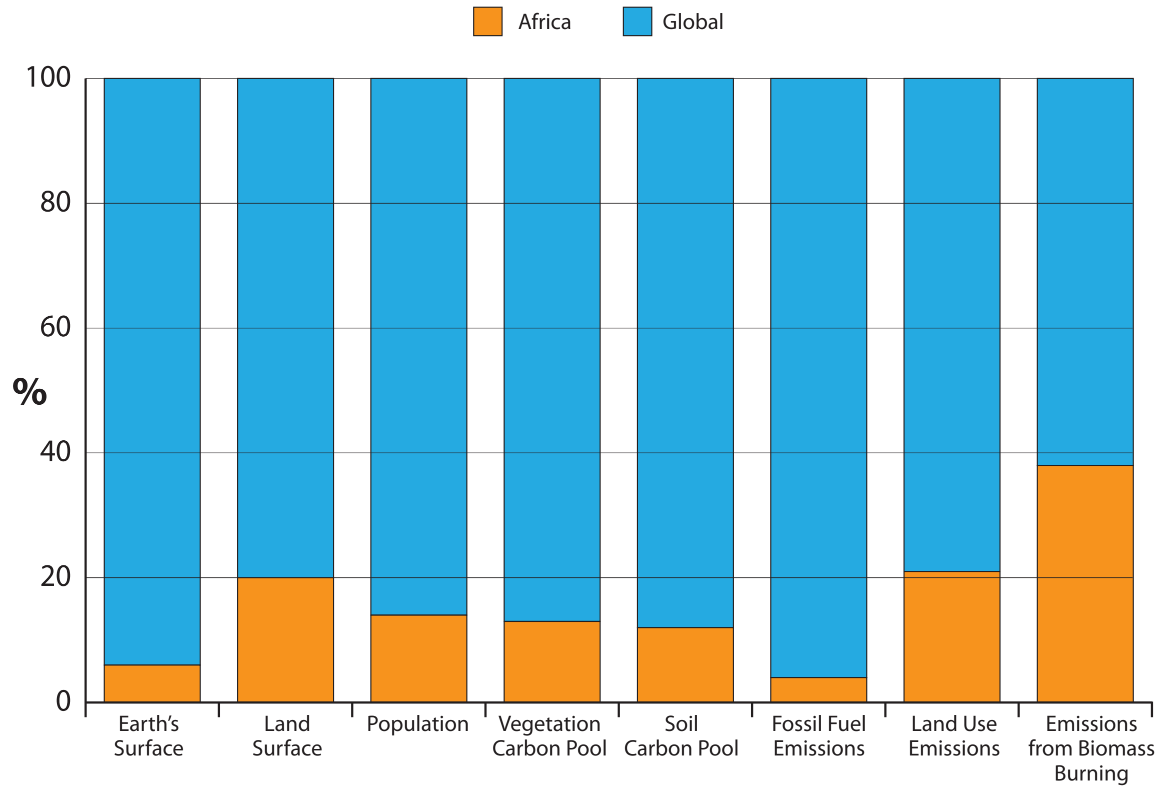
In addition, SOC varies with depth and soil type. In Leptosols (shallow soils over hard rock or gravel – see page 55) virtually all of the SOC is located in the 0–30 cm layer. In contrast, Histosols (organic soils also known as peat) can be several metres thick.

Soil carbon and ecosystems

The relationship between soil carbon content and ecosystems shows some interesting features. Using the Terrestrial Ecoregions of the World database of the World Wide Fund for Nature as a base, the soils with the highest mean SOC content, as expected, are found in the wet mangrove ecosystem with a mean carbon content of 6.61 kg m^{-2}. Similarly, there is no surprise that the deserts and dry shrublands ecosystem exhibits the lowest carbon content with only 1.53 kg m^{-2}, reflecting the limited biomass production and poorly developed soils of arid regions. Higher net primary production in tropical regions, coupled with deep soils, give very high carbon content to the soils of tropical and subtropical moist broadleaf forests (5.7 kg m^{-2}). Soils in tropical and subtropical dry broadleaf forests (5.0 kg m^{-2}) and flooded grasslands and savannahs (4.17 kg m^{-2}) also contain significant levels of SOC while levels are significantly lower in mediterranean forests, woodlands and scrub (2.83 kg m^{-2}) and montane grasslands and shrublands (3.47 kg m^{-2}) [46].

However, total SOC stocks also depend on the geographical extent of a soil. In this context, the graph below demonstrates that the most important stock of soil carbon to a depth of 1 m is stored in the tropical and subtropical grasslands, savannahs and shrubland ecosystems, holding around 80 000 Tg C*. Due to their small extent, the temperate conifer forests and mangrove ecosystems contain relatively low C stocks. Further investigation of the distribution of carbon within soil shows that in all ecosystems, SOC is concentrated in the topsoil. The slightly higher values in the subsoils of flooded grasslands and tropical moist broadleaved forests may reflect conditions that facilitate the leaching of carbon deeper into the soil (however, the reader should note that the values for the subsoil relate to more than twice the depth of the topsoil). These figures demonstrate that the topsoil is the most important SOC pool, yet it is also the most susceptible to manipulation by human activities and climatic variations which, together or singularly, can lead to the loss of soil carbon and degraded soils.

* Tg = a teragram, 10^{12} grams equivalent to 1 million (10^6) tonnes (megatonne) or 1 billion (10^9) kilograms



A global perspective of Africa with regard to carbon. For comparison, the soils of the northern circumpolar regions (i.e. above a latitude of 50° North) contain about 25% of the global terrestrial vegetation carbon and approximately 50% of the terrestrial soil carbon pool. It should be noted that data for African pools and sinks are very imprecise and that the uncertainties associated with these values can be very large. (JRC) [Emission data 43, 47]

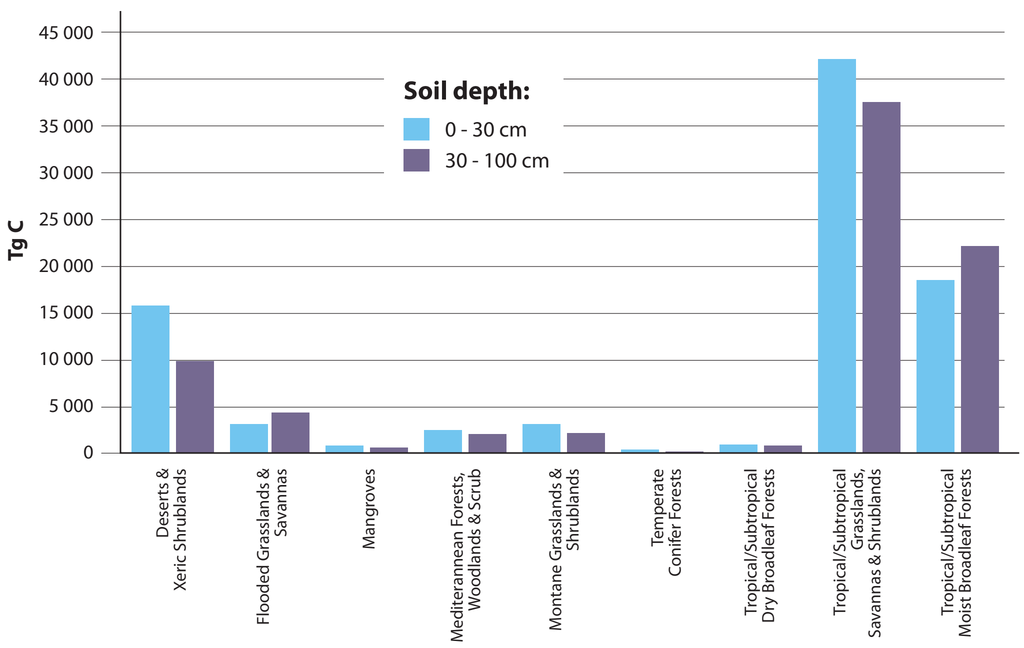
A profile of a Phaeozem from Tanzania – a soil that develops under natural grasslands in sub-tropical/sub-temperate climates. There is enough rainfall to support the vegetation and the organisms that drive the decomposition process. Soils, especially topsoils, that are rich in organic matter appear dark in colour and will show a gradual lightening with depth – very evident in this photograph. Dark-coloured soils absorb heat, warm up more rapidly and cool down less rapidly. Plants such as grasses contribute to soil organic matter through their extensive fibrous root mats and, to a lesser extent, litter fall on the surface. Over time, soil under grasslands, such as this Phaeozem or Kastanozems and Chernozems, can accumulate large amounts of soil organic matter. The conversion of natural grasslands to agricultural use causes considerable losses of organic matter. (SH)

The soils of Africa in the global carbon cycle

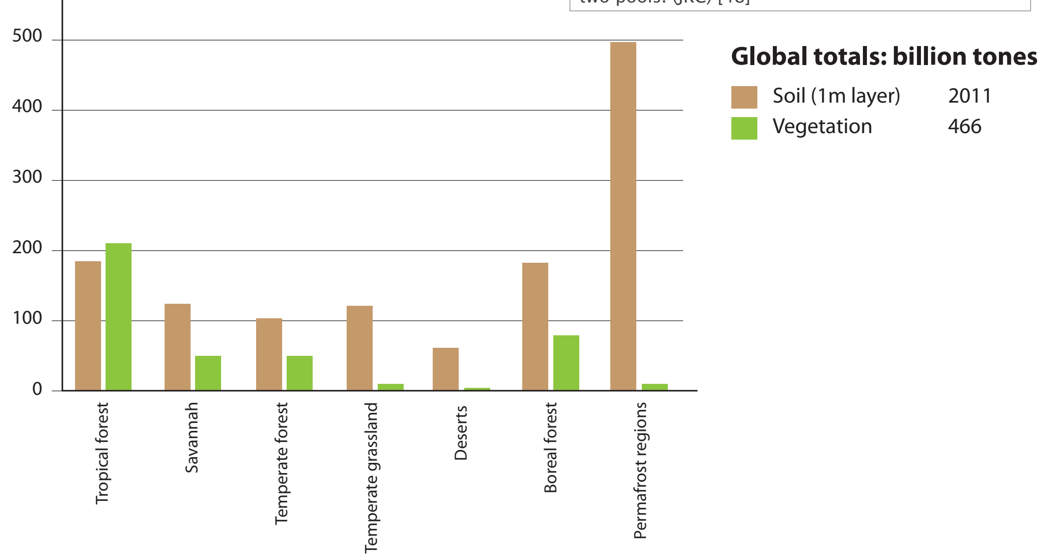
The graph above presents a global view of Africa from a carbon perspective. While occupying 20% of the Earth's land surface and being home to 14% of the world's population, Africa contributes only 4% of the global fossil fuel carbon emissions that are responsible for rising atmospheric carbon dioxide concentrations (0.2 Pg C yr^{-1}). This is a disproportionately small fraction but reflects the rural and under-developed nature of the African population. However, Africa generates more than one-fifth of the global emissions from land use (i.e. deforestation and land use change) and, staggeringly, nearly 40% of global emissions from burning biomass (i.e. deforestation, shifting cultivation, savannah fires, fuel wood, agricultural residues, etc.). Both the vegetation and the soils of Africa occupy a similar global proportion, about 13% and 10-12%, respectively. [47, 47a]

The graph below shows the amount of carbon stored in the soil (to a depth of 1 metre) and vegetation of the main ecosystems of the planet. The figure clearly illustrates the huge capacity of soil to store carbon compared to vegetation and emphasises the key role that soil plays in the terrestrial global carbon cycle. The only ecosystem approaching parity between carbon stores in vegetation and the soil is the tropical forest. This is due to the lush and continuously growing vegetation and the rapid recycling of litter and plant remains into the soil. However, the graph also shows clearly that the main reservoirs of global land-based carbon are the cold permafrost regions and ecosystems such as the boreal forests.

Topsoil and subsoil organic carbon stocks in major African ecosystems. (JRC) [46]



A comparison of organic carbon pools in the soil and the vegetation of major ecosystems. Permafrost affected soils are the principle terrestrial carbon pool while in the tropics, there is a balance between the two pools. (JRC) [48]

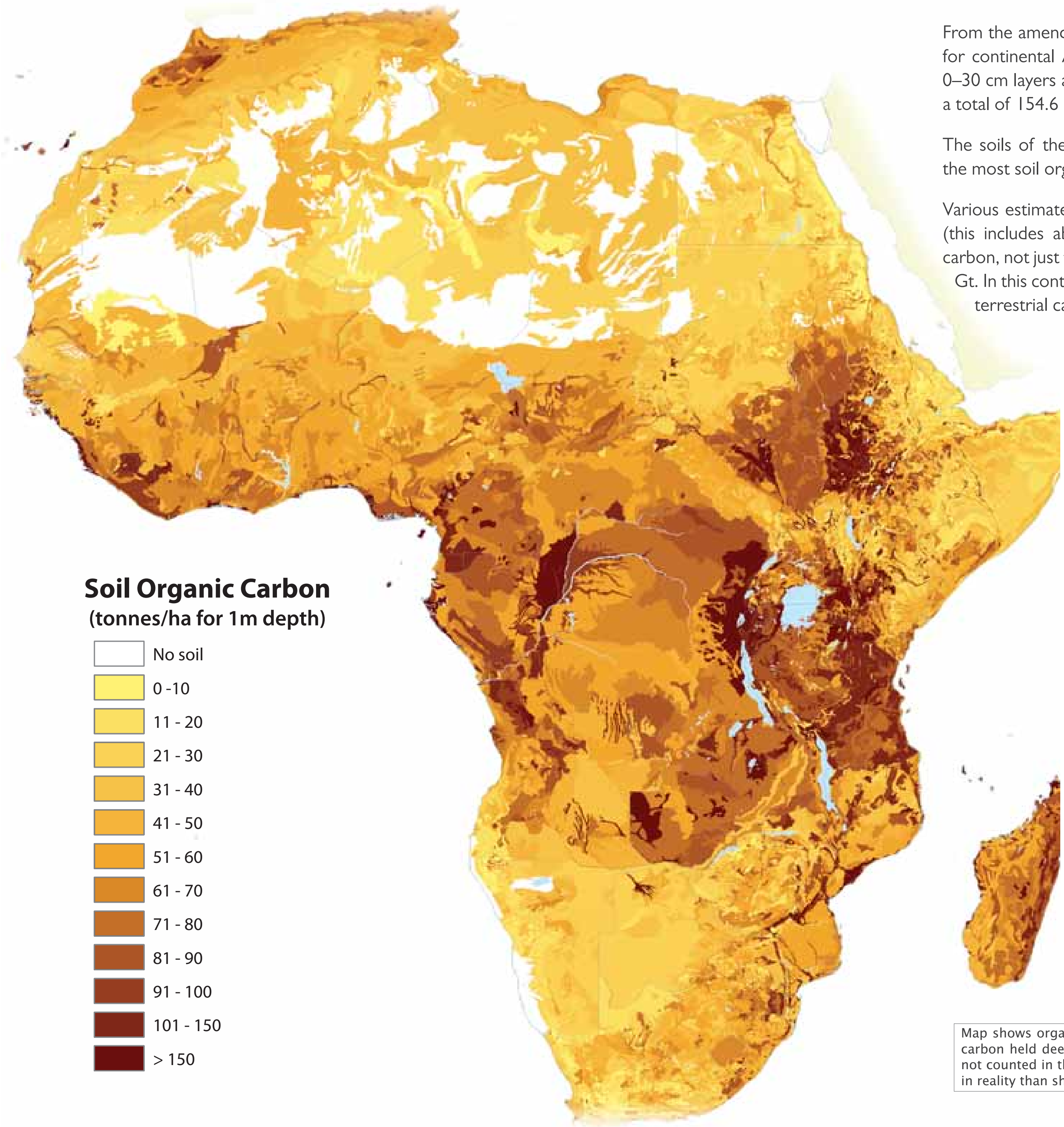


How much organic carbon is there in the soil of Africa?

From the amended version of the HWSD [49], soil carbon stocks for continental Africa have been calculated as 80.1 Gt C for the 0–30 cm layers and 74.5 Gt C for the depth 30–100 cm (this gives a total of 154.6 Gt C for 0–100 cm depth).

The soils of the Democratic Republic of Congo and Sudan hold the most soil organic carbon with 19.11 and 12.65 Gt respectively.

Various estimates place the total terrestrial carbon pool of Africa (this includes above ground vegetation and also all soil organic carbon, not just that in the upper 1 m) at between 250 000–280 000 Gt. In this context, soil holds between 55-70% of the total African terrestrial carbon pool.



Map shows organic carbon in the uppermost 100 cm of soil. Organic carbon held deeper than 100 cm (e.g. deep peats, estuaries, etc) are not counted in this exercise. Consequently, there is more soil carbon in reality than shown by this map. (JRC/RHR) [49]

The map on this page represents the distribution of soil organic carbon densities in Africa to a depth of 100 cm from the surface in tonnes C per hectare (t C ha^{-1}) with a resolution of 3 arc seconds. The calculations are based on data from an amended version of the Harmonized World Soil Database (see page 136).

The colours on the map correspond to the amount of organic carbon in the soil. Lighter tones indicate the lowest concentrations of organic carbon while darker tones indicate higher amounts. SOC varies according to temperature, moisture, local soil conditions and land use. Four main zones stand out: the very low arid regions, temperate grasslands, tropical forests and grasslands and wetlands. The maximum SOC densities were found in Rwanda (214.6 t C ha^{-1}) and Burundi (166.7 t C ha^{-1}) while the minimum SOC densities were found in arid Djibouti (15.1 t C ha^{-1}) and Mauritania (20.3 t C ha^{-1}). The average SOC content is 35.08 and 31.83 t ha^{-1} for the 0–30 cm and 30–100 cm soil layers, respectively. [49]

Most of the carbon stock of the continent is located in central Africa. Levels for much of northern and southern Africa are relatively low.

The reader should note that there are uncertainties in any estimate of soil carbon stocks at national and continental scales and the uncertainty of the information presented here is high. More confidence can be attached to information from regions with more detailed soil inventories (the Mediterranean parts of North Africa, South Africa and parts of Eastern Africa).

Significant additional effort would be required to improve the estimates and spatial resolution of the soil biophysical properties and the impact of human activities.

Abrupt boundaries in the map may reflect disparate soil datasets.

In the tropics, looks can be deceptive!

With no winters or frosts to kill insects or microorganisms, and constant heat and humidity to drive decomposition, organic carbon levels are generally low in most mineral forest soils of the tropics. Iron oxides (hematite) tend to dominate giving soils a reddish appearance. However, both of the soils shown in the photographs **below**, from Ghana, have as much organic carbon (about 14 kg C per m^2) as a temperate grassland in Denmark. In these cases, the organic matter has been stained red by the iron. (TB)

Soil and the hydrological cycle

Water is essential for the survival of almost all living organisms and soil plays a key role in the global hydrological cycle. Most of the rain falling in Africa is intercepted by vegetation or falls directly onto the soil surface. Once the leaves and branches have been moistened, any excess water drips from the canopy or runs down stems and trunks to the soil. Depending on factors such as soil moisture status, texture, organic matter content, soil structure, precipitation intensity and duration, rainwater may:

- soak into the soil body where it may be stored for plants to use;
- percolate downwards through the soil to recharge the water table or aquifers;
- flow horizontally or laterally through the soil to feed rivers, lakes or springs;
- be intercepted by roots growing through the soil.

The movement of water into the soil from the surface is known as infiltration, while the passage of water through the soil is referred to as percolation. Coarse textured soils such as sands and gravel usually have high infiltration rates. When precipitation rates exceed infiltration capacity (due to either prolongued or intense rainfall), or if the soil is full of water (saturated) or crusted (after dry conditions) or there is a subsurface impediment to drainage, water may run over the soil surface as runoff or overland flow, often directly into streams and rivers – this process is also a significant type of soil erosion (see page 155).

As water infiltrates into the soil, water in larger pore spaces and channels will move to lower levels under the force of gravity. In addition, capillary forces can bind water to soil and organic matter particles and even pull it through very small pore spaces, even against the force of gravity. If the volume of water entering the soil is small, then the moisture may only be attached to the surface of particles and the spaces will be empty. In hot climates, evaporation can move water towards the surface.

When a soil is saturated, all soil pores are filled with water and virtually all of the air in the soil has been displaced by water.

Depending on the soil characteristics, water may take several days to drain through the soil profile although some water can be absorbed by roots. Field capacity is defined as the level of soil moisture left in the soil after the removal or drainage of water from saturated conditions (48 hours after saturation).

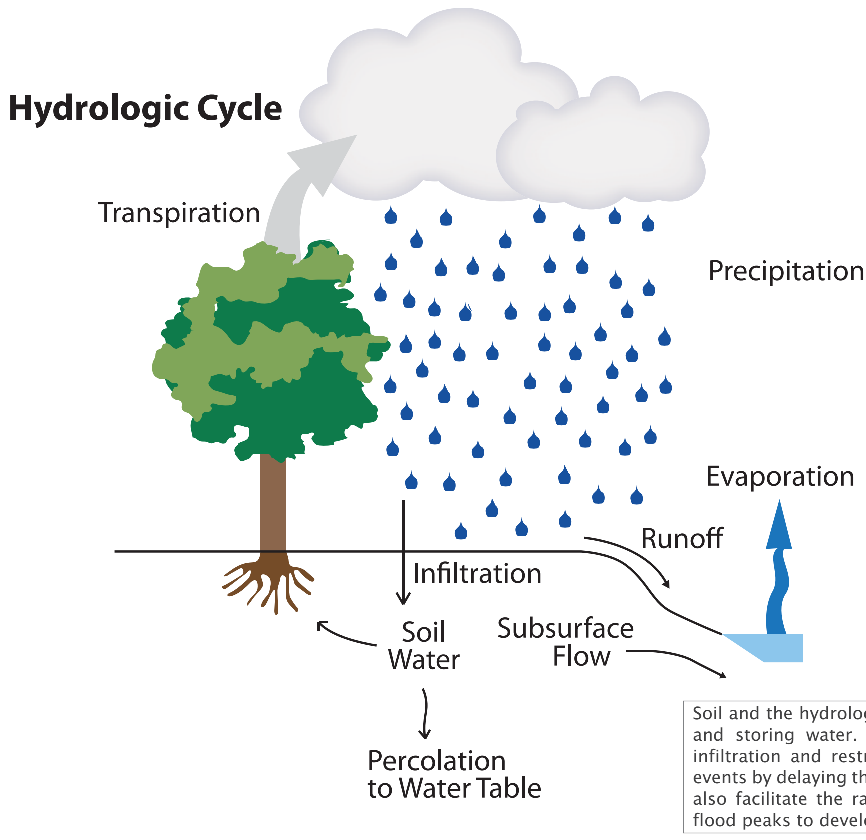
The wilting point is defined as the soil moisture content where most plant roots cannot exert enough force to remove water from small pores in the soil. Most crops will be damaged if the soil moisture content is allowed to reach the wilting point.

Understanding soil hydrological processes is important for cultivation, flood prevention and erosion control. Soils with very dry moisture regimes require irrigation to be used for crops. Soils in semi-arid moisture regimes can support rain-fed crops, but moisture will be limited during some of the growing season and some irrigation may be required. Soils in humid climates have sufficient moisture for crops without the need for irrigation. Very wet soils will require artificial drainage for most crop growing practices.

The general patterns of soil moisture across Africa are displayed on the map on page 18. Most of central and southeast Africa have moist soils all year round as rainfall is greater than evapo-transpiration rates. The soils of the savannah regions are generally dry in the summer months with a single, distinct wet season. A large part of the continent is desert, where soils are dry for significant periods. In the Mediterranean coastal zone and around the Cape of Good Hope, soils are generally moist in winter but dry in summer.

The Sahel

The Sahel is the climatic and biogeographic zone of transition between the southern extent of the Sahara desert and the less arid savannah. It stretches across the entire African continent between the Atlantic Ocean and the Red Sea. The word literally means "shore" in Arabic as it describes the appearance of the vegetation as a coastline delimiting the barrenness of the desert. The Sahel includes parts of Senegal, southern Mauritania, Mali, Burkina Faso, southern Algeria, Niger, northern Nigeria, Chad, northern Cameroon, Sudan, Southern Sudan and Eritrea.



Soil and the hydrological cycle. Soil acts like a giant sponge absorbing and storing water. The sealing of soil by artificial surfaces limits infiltration and restricts the ability of soil to mitigate against flood events by delaying the arrival of water to river channels. Sealed surfaces also facilitate the rapid transport of water to river systems, causing flood peaks to develop sooner. (CSS)

These two profiles illustrate contrasting soil moisture conditions on hillslopes in the Weatherley catchment of the Eastern Cape Province of South Africa. The top profile is freely draining, well aerated and lying at the top of the slope. Excess water drains to the underlying rock and recharges the regional water tables. The lower profile shows a typical low-lying, saturated wetland soil where the water table is visible. (PLR)

How do plants take water from soil?

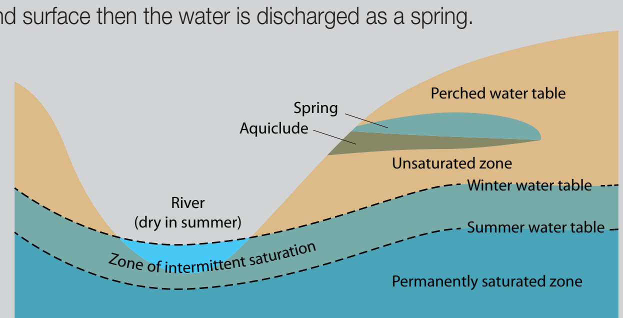
Plants can use only the water that is in direct contact with their roots. For most crops in a deep uniform soil, the root distribution is concentrated near the soil surface. Plants such as grasses, with a high root density per unit volume of soil, may be able to absorb all available soil water. Conversely, vegetables, with a low root density, may not be able to obtain as much water from an equal volume of the same soil. As a result, vegetables are generally more sensitive to water stress than high root density agronomic crops such as corn, wheat and sunflowers. Over the course of a growing season, plants generally extract more water from the upper part of their root zone than from the lower part.

Water table, springs and watering holes

An important feature of the African landscape, especially in climates with low rainfall or distinct rainy seasons, are watering holes. Such features are important in supporting natural wildlife and grazing animals such as cows or goats.

Elephants at a watering hole in South Africa. (MF)

Watering holes are depressions in the ground where water held by the soil comes to the surface. The upper limit or surface where the soil is saturated with water is known as the water table. The position of the water table reflects the surface relief but may vary due to topography, soil type and seasonal changes in precipitation or evapotranspiration. Springs, rivers, lakes and oases occur when the water table reaches the surface. Perched water tables occur above the regional water table when an impermeable barrier (aquiclude) prevents the downward flow of water through the ground. If a perched aquifer's flow intersects the land surface then the water is discharged as a spring.



Main components of the water table. (after WikiF/LJ)

Soil biodiversity

Soil is sometimes referred to as a biomantle, emphasising the fact that soil is a product, to a large extent, of biological activity. The majority of the vital soil functions described in the previous pages depend on the diversity of life that exists within it – soil biodiversity – ranging from genes and species to communities of organisms [50, 50a].

- A single teaspoon of fertile soil may contain thousands of species, millions of individuals and hundreds of metres of fungal networks.
- Scientists estimate that at least about one-quarter of species on planet Earth live in soils.

African soils contain an extraordinary range of taxa and species with varying body sizes, populations and activity. Some animals that lack size often make up for it in numbers. Soil may benefit animals in a variety of ways. It provides shelter, a breeding ground, waste dump, source of food (animal and vegetable), dietary supplement (geophagy) and means of hygiene (dust and mud baths). In their use of soil, animals can change its characteristics. The mixing of soil particles (bioturbation), decomposition of organic matter and nutrient cycling are heavily dependent on biological activity.

By burrowing and nesting, animals such as termites, ants, earthworms, moles, rodents, mongoose, birds and even large herbivores, mix and aerate soil layers. They create passages that aid the infiltration of rain and hasten the recycling and mineralisation of nutrients, both by direct digestion, and by disturbing litter. In fact, many creatures bring organic matter from the surface and deposit it deep in the soil. The consequences for soil porosity, aeration, water storage, drainage, bulk density, erodibility and nutrient status are profoundly important, both ecologically and economically. Indeed, thriving populations of invertebrates and microorganisms are regarded as a cornerstone of soil health.

In turn, soil fauna depend for their energy and nutrients on plants which in turn depend on soils in the first place. Both the aardvark and fungus-culturing termites (which make large earth mounds) could be regarded as 'ecosystem engineers.' For example, the aardvark is powerful enough to generate a surplus of deep burrows which in turn promotes warthog populations by providing protection from predators and allows these pigs to survive as both large herbivores and important soil excavators in their own right.

Similarly, fungus-culturing termites build and maintain large and sophisticated arrangements of chimneys and chambers to ensure oxygenation and humidity in their fungus cultures, which not only provides living space for many animals such as the dwarf mongoose (*Helogale parvula*) and the giant land lizard (*Varanus albigularis/ exanthematicus*) but also modifies soil fertility to such a degree that some regard it as 'farming' by an insect.

One possible explanation for the extreme expression of soil fauna in Africa is a combination of switch effects and synergy. Subtle variations in the availability of critical catalytic nutrients can be amplified by ecological feedback loops and tipping points that culminate in categorical changes in the fauna.

Understanding soil biology relationships can have enormous practical significance. In the rehabilitation of land destroyed by strip mining, the most difficult problem is to find ways of alleviating soil compaction. Restoration is doomed to failure if attention is devoted to revegetation at the expense of finding ways to repopulate the soil with a self-sustaining array of animals - large and small. In agriculture, the current drive to pursue conservation farming methods requires that similar attention be given to achieving a healthy population of organisms capable of effecting bio-tillage.

While soil biota may be out of sight (and possibly out of mind?), taking steps to protect them may be doubly useful as efforts to protect soil communities are very likely to help conserve better-known endangered plants and animals that live above-ground. [50]

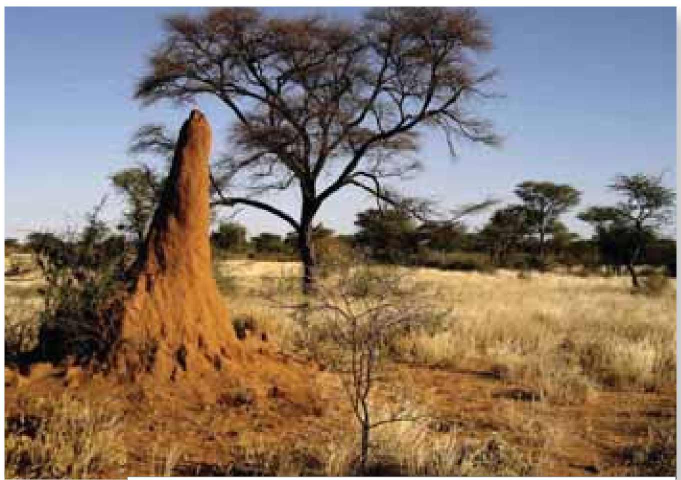
An aardvark (*Orycteropus afer*) in the Mapungubwe National Park, South Africa. The aardvark is a burrowing, nocturnal mammal that is native to Sub-Saharan Africa. They feed almost exclusively on ants and termites and can be regarded as the top of the soil food chain. Some researchers have estimated that one aardvark can consume up to 50 000 ants in one night. In addition to living in the soil, their old burrows are used by other mammals. (SC)

Termites and Soils

Termites are a group of soil-living, social insects, taxonomically known as *Termitoidae*, of the cockroach order Blattodea.

While there are similarities, termites are only distantly related to the ants. Many species of termites occur in Africa, ranging from the soil-feeding and mound building Cubitermes to the litter-feeding Macrotermes. As their diet consists of organic material mixed with clay minerals, termites play an important role in soil formation and nutrient recycling. They are soil miners and soil architects, building impressive mounds in all sizes and shapes with soil they extract from great depths. Termite mounds are a common sight in the landscapes of Africa.

- termites are a major source of income and protein for many rural households, where they are consumed during the rainy season;
- in savannah areas, the soils of termite mounds are used to increase soil fertility as levels of P, K, Ca, Mg and organic C are usually higher in the centre of mounds than in the adjacent soil;
- termite mounds are used for brick making as the soil tends be clay-rich. Termites build their mounds by bringing up clay particles from the subsoil to the surface and then bind them together by secreting a natural glue-like substance from their saliva;
- termite mounds are often inspected during geochemical prospecting for various metal ore deposits such as tin, silver, gold, uranium and diamonds. Termites can go to considerable depths to obtain moist soil to build their mounds and as such may bring up small samples of minerals.



A termite mound in Namibia. Mounds in tropical savannahs can be very large, some up to 9 m high. In drier savannahs, two to three metres is more typical. The shape of the mound can be indicative of the termite species (but not always!). (AM)

Above: The giant African millipede (*Archispirostreptus gigas*) can grow up to 40 cm in length and have more than 200 legs. It is widespread in lowland parts of East Africa, and rarely recorded above 1 000 m. While millipedes and other invertebrates are critical to many soil functions, our knowledge of soil biodiversity in tropical Africa is very limited. (BCT)

Below: a striking example of the relationships between above and below ground biodiversity. Organic matter (in the form of bird excrement) dropping from the nests of weaver birds in Namibia provides just enough nutrients to support initial soil development and microbial communities in an otherwise semi-arid environment. (EM)

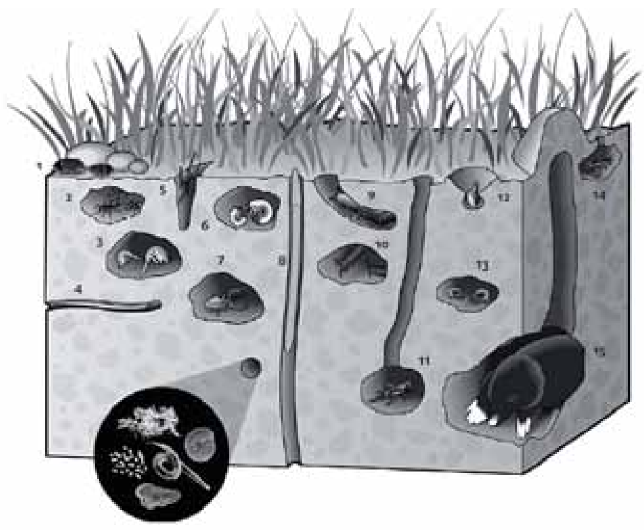
The Debe Hollows: a unique soil

The soils of the Kommetjie Veldt (Afrikaans for small cup; known as Malinda in Xhosa or Debe Hollows in English) are unique in Africa, if not globally. In an area of about 1 000 km^2 in the Eastern Cape Province of South Africa, the land surface is characterised by a surface micro-topography of mounds 60 cm to 80 cm high, with mixed soil horizons, subsoil mottling and lintwhite formation. Their origin is due to the activity of the giant African earthworm (*Microchaetus microchaetus*) which can grow to about 14 mm in diameter and over 6 m long! This is a clear example of a living organism being the dominant soil-forming factor.

Soil water conditions must be ideal for the earthworms to grow to this size. Mounds are raised above the water table and serve as their habitat during subsoil saturation. South-facing slopes generally have more earthworm activity as they are wetter and cooler. The casts of earthworms are more fertile than the surrounding soil, containing more phosphorus, calcium and much more exchangeable manganese (Mn). That implies that Mn is reduced in the earthworm gut and this process plays an important role in the formation of soil mottles and manganise-rich concretions. [51, 51a]

Debe Hollows near Dimbaza, Eastern Cape, South Africa. The hummocky landscape in the middle ground is due to the churning of the soil by the giant African earthworm. (TD)

A giant African earthworm *(Microchaetus microchaetus)* from the Eastern Cape Province, South Africa. (AM)



Workers in the factory of life come under the microscope: bacteria, nematoide, fungal mycelium, protozoans

1. Woodlice
2. Ants
3. Springtails
4. Under soil earthworm
5. Spider
6. Cockchafer larvae
7. Pseudoscorpion
8. Deep burrowing earthworm
9. Slug
10. Myriapods
11. Field cricket
12. Ant-lion larva
13. Mites
14. Common earwig
15. Mole

There's not only life on Earth, but in it as well. The diagram **above** shows some examples of life in the soil and their habitats. The amount of living matter contained in soil makes it the original renewable energy source. Some people refer to soil as the factory of life. (EC/LJ) [50]

Cultural heritage and trade

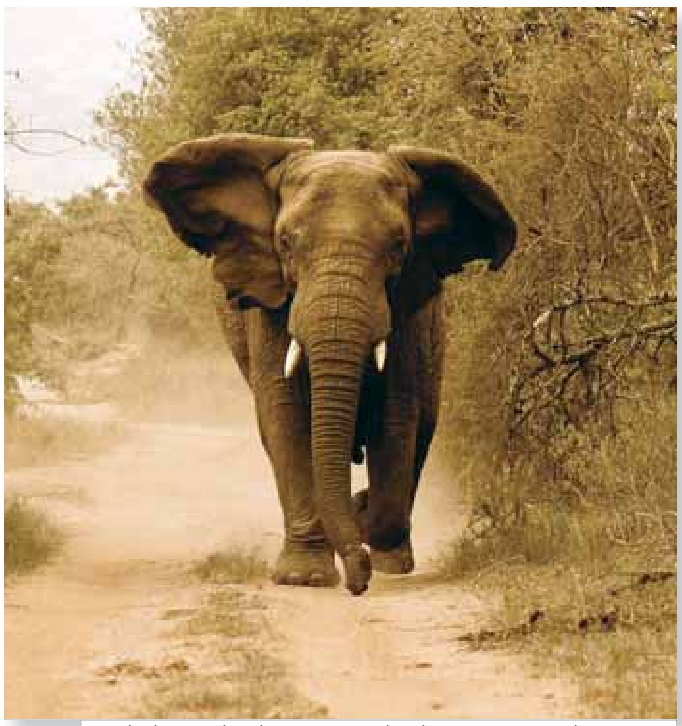
Preservation of cultural heritage and landscapes

Soil stores and protects much of our cultural heritage, including archaeological remains and landscapes. The soils of Africa are full of heritage [52]. Over long periods of time, indigenous communities have moved across the landscape, making use of its resources and by their activities modifying the environment. These communities have left signs and products of their activities across the continent, buried in the soil, sometimes in great numbers. There are many examples where objects preserved in soil have been used to understand history, often when no other evidence remains. The remains of dwellings can be identified from the outlines of ditches and postholes in soil through variations in texture and colour, charcoal from hearths can be dated while the remains of animal bones, settlement debris and plant remains can give an insight into past environments. A glimpse into society and beliefs can be obtained by investigating burial practices, grave artefacts and fragments of pottery or art. This last aspect is especially evident along the Nile Valley, in the Horn of Africa and along the North African coast.

Soil characteristics are critical in determining the preservation of an object. Being of organic origin, wood normally decays under combined biological and chemical attack when buried in the ground or submerged in water. However, it can survive for very prolonged periods in either a very dry or a completely waterlogged environment. In the same manner, organic matter decomposes much more rapidly in well-drained soils where well-preserved organic remains are usually scarce. In contrast, metal objects survive better in aerated conditions leading to the preservation of metal weapons, ornaments, jewellery and coins. Acid soils are rather aggressive in decomposing artefacts, especially iron. Pottery, ceramics and glass tend to survive in most soil conditions.

In addition, soil conditions often shape distinctive habitats or, together with specific land management practices, produce specific habitats and characteristic landscapes that are valued by society at large. For example, the wetlands of the Okavango and the open grassland and distinctive acacia tree of the Masai Mara are products of specific soil-climate interactions in the same manner as the tropical rain forests and oases in the deserts. Fertile soils give rise to agricultural landscapes such as the vineyards of South Africa or the olive groves of the Mediterranean. It should be remembered that the location of most urban sites were selected because they also provided a stable food supply to their resident populations.

It is important that soils with high or potential cultural heritage aspects are managed in a manner that preserves these features. Cultivation practices should be controlled, for example, by avoiding deep ploughing if archaeological remains are in the topsoil. Similarly, the risk of erosion, acidity/alkalinity levels and desiccation should be controlled if possible. Cultural 'erosion' of such traditional knowledge about soil is still responsible for the loss of a significant number of languages and their unique information, knowledge and conceptual systems about humans and nature, often acquired through experiential and insight learning.



An elephant in the Akagera National Park in eastern Rwanda. Tourism is a significant aspect of the economy of several African countries (e.g. Botswana, Kenya, Tanzania). The habitats that support the animal populations are heavily dependent on specific soil characteristics to support the vegetation and associated food chain. (AL)

Soil and culture: a traditional perspective

From a traditional perspective, land is considered as a sacred heritage, which needs care during its use and management. It is perceived as a lively environmental body, which represents the beginning and the end of life. Traditional communities see land as an asset and spiritual environment, which merits a lot of respect and attention as food and water provider. Land perception is part of a cosmogony and a cosmos vision developed by traditional communities such as the Dogon people in Mali. Its use is subject to rituals (for example, in the Sourou region in Burkina Faso and the mountainous areas of Lesotho).

Land is also an expression of power, strength and security for a given community. In most land tenure systems, common land represents open areas. However, freedom of land use fits within traditional systems of 'taboos' in conformity with unwritten rules.

Traditional or indigenous knowledge about land resources is "local knowledge that is unique to a given culture or society" and is based on careful observation and use of the societal resources. This local knowledge is the basis for the development of diverse ingenious natural resource management heritage systems throughout the continent.

Examples of cultural heritage and land management include:

- Floodplain recession management (e.g. Senegal, Niger and Sokoto rivers);
- Traditional Masai rangeland management systems in Kenya, providing scenic beauty and wildlife diversity with immense recreational value;
- Oases in deserts where spring water and irrigation sustain social services and an agro-ecosystem;
- The sophisticated land use system of the Konso (Ethiopia) which allows them to subsist in a mountainous area with fragile soils and erratic rainfall;
- Traditional sand dune management in the Sahel region that supports agricultural production through the use of a low soil disturbance tool (iler) and the improvement of soils with domestic waste and organic manure.

Archaeological excavations in Cameroon. Recent studies have led to the discovery of thousands of historical sites and archaeological remains hitherto unknown or inaccessible. Here, more than 400 arrow tips and iron spears dating from the eighteenth century have been unearthed in a Ferralsol near to the town of Kribi. (RO/IRD)

Soils and trade

It is difficult to over emphasise the importance of soil for the economy of Africa as about two-thirds of Africans depend on agriculture or trade in agricultural products for their livelihoods. The fate of agricultural production is largely determined by the condition of the soils, therefore, soil directly affects economic growth, social improvement and trade in Africa. For instance, the famous wine producers of South Africa focus on identifying sites with soils developed from granite, table mountain sandstone and shale in order to produce grapes with the necessary character and complexity.

The impact of trade on the management of soils is varied but unfortunately often results in soil depletion and degradation. The demand for 'raw materials' (e.g. iron, diamonds, gold, phosphates, coal, uranium, etc.) is a major cause of soil losses in many African states, either from mining activities or contamination. Trade in agricultural products, - often a major feature of structural adjustment policies – has led to an increase in the area devoted to export crops. In many cases, the impacts have been significant and harmful to soil quality. A study in Mali, for example, found that the development of cotton as a cash export crop substantially increased the cultivated area and affected soils through a markedly reduced fallow period. The profitability of cotton, cocoa, coffee, tea and other crops led farmers to expand cultivation onto marginal land, resulting in increased land degradation and soil erosion. On the other hand, export crops may sometimes be more soil-friendly than the domestic crops they replace. In parts of eastern and western Africa, tree crops such as coffee and cocoa have helped to prevent erosion by stabilising soils. Horticulture provides a high-value export and is claimed to have limited effects on soil quality, although concerns have recently been raised about the health of workers and the environmental effects of the inappropriate use of pesticides.

The resulting depletion of nutrients from soils has caused agriculture production to stagnate or decline in many African countries. In some cases, notably in the East African highlands, the rate of depletion is so high that even drastic measures, such as doubling the application of fertiliser or manure or halving erosion losses, would not be enough to offset nutrient deficits. If nutrient depletion and land degradation continue at current rates, one has to wonder how farmers in African countries will be able to produce enough crops to trade and to provide food for ever-larger populations. Unless African governments take the lead in confronting the problems of nutrient depletion, deteriorating agricultural productivity will seriously undermine the foundations of trade in Africa.

The dumping of industrial wastes is another hazard for African soils. From statistical indications, the protocol of the Basel Convention has failed to protect African soils and its people against the crime of illegal hazardous dumping by some unscrupulous industrial operations. For example, in 2006, 500 tonnes of toxic wastes were dumped in the soils of the Côte D'Ivoire; in 1992, 10 million tones of toxic waste were disposed of in Somalia; in 1989, 15 000 tonnes of pharmaceutical waste were dumped in Guinea-Bissau; many other events have not been recorded.

Examples of preservation of cultural heritage by soil. **Top left**: Olive trees being cultivated in bunded enclosures in an ephemeral channel in Tunisia. Olive cultivation has been carried out in North Africa for several thousand years and is an important cultural aspect of the region. The bunds harvest runoff and irrigation water during the dry season. In addition, fine particles of nutrient-rich eroded soil are captured by these micro-dams thus enhancing the fertility of the land. (TG); **Middle left**: the Pyramids of Meroe in Sudan, an ancient city on the east bank of the Nile approximately 200 km north-east of Khartoum. Built approximately 2 500 -3 000 years ago, writing tablets, statutes and pottery have been preserved in the dry sandy soils. (FD); **Bottom left**: soil conditions and land management practices often shape distinctive habitats or landscapes such as this terracing system in the highlands of Malawi. (MAP)

Soil as a source of raw materials

In Africa, soil has been used as a raw material for making, producing and manufacturing various goods and services for thousands of years. In many places, these practices continue to this day. The main uses include:

Construction

Various types of houses are built by using soil as a construction material. Soil is used for roofing and thatching houses in arid and semi-arid areas of Africa where other thatching material is unavailable. Houses with soil or green roofs are heat and cold absorbers and make the dwellings more comfortable to live in.

Clay is used to make bricks of different sizes, colours and shapes. Clay roofing has been used as roofing and thatching material for a very long time. Bricks made of clay are used for walls in modern and as well as ancient buildings. The Great Mosque of Djenné (Mali) is the largest mud brick or adobe building in the world and is considered by many to be one of the architectural wonders of the world (see page 11). Brick-walled houses are very strong and again absorb heat and cold. Brick-walled houses are also durable, provided that timely maintenance is carried out. Some of the soil types used for different housing include plinthite as bricks for building houses, loamy to clay soils for plastering straw houses while sand is used for mixing with cement for rendering, mortar and concrete making. Most dwellings in rural areas are plastered with soils mixed with crop straw to make it resistant to cracking.

Soils also provide major building material in road construction. Pisolithic gravel is used widely for roads and air strips. Rocky soil is used as final fill in roads, in most cases the outer cover of dam walls is made from sandy loam soils while the cores of dam walls are often made from Vertisols or other soils containing swelling clays.

Finally, many roads in rural Africa are unsurfaced with vehicles being driven on the soil surface. In wet conditions, traffic can cause the surface to deteriorate, making the road impassable.

Utensils

Many rural inhabitants throughout Africa use clay, especially kaolinitie, to make a variety of pots, cups, kettles and pans. In fact, earthenware is one of the oldest materials produced by humans. While less strong, less durable and more porous than stoneware, earthenware is also less expensive to produce and much easier to work. Due to its higher porosity, earthenware containers must usually be glazed or baked in order to be watertight. Soils with very high kaolinite clay contents are thus seen as a valuable local resource. Many kinds of food and drink are prepared using such utensils while earthenware jars are used to store grain for brewing beer. While red earthenware made from red clays is very familiar, other colours can be found depending on the chemistry of the clay. Some communities make drinking glasses from sandy soil while sand-filled containers are used for cooling food or drinks. Bags filled with sand are often used to slow the thawing of frozen items.

Household furniture

In many African rural areas, beds, seats, benches and cupboards are constructed of soils. Crop residues and/or hay are mixed with soil and water in a large pit to make it strong and increase its plasticity. The more plastic the mud the stronger it becomes. The objects are then shaped by hand or in moulds as required.

Ornaments and ritual/spiritual objects

Soil is used to make ornamental or decorative objects. Cosmetics for painting faces are usually soil-based. Soil-made items are used for celebrating traditional beliefs and also serve as objects of worship.

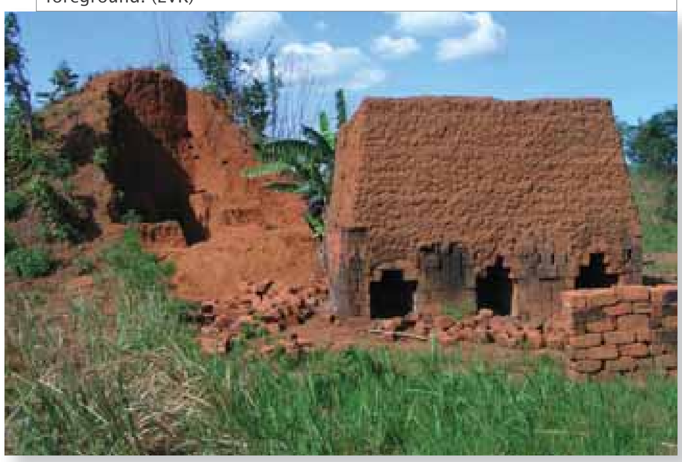
Recreation

Topsoil is used for levelling and filling gardens and lawns while sport turf is grown on selected soil types. Coarse sand is used for building golf greens and sand 'hazards'. In Kenya and South Africa, Vertisols are used as "bully" in the construction of cricket pitches while Ferralsols or their equivalents are used for clay tennis courts.

Medicinal and food/nutrients

In some areas people eat clay soils as a medicine for treating diarrhoea and use them for treating skin diseases or ulcers. In some traditions (such as Uganda), pregnant women use clay from termite mounds as a source of minerals. Animals such as birds use sand to enhance digestion of food in their gizzards. Bentonite is used as a nutrient. Soil is also a source of salt for animals. Many antibiotics are based on soil fungi (e.g. *Penicillium notatum*).

Above: Houses bricks being made from a silt-rich soil (Planosol) in Ethiopia. The worker is simply digging out the topsoil and placing it in a mold. Houses made out of mud bricks with roofs made from woven branches can be built quickly and cheaply and exist in practically all cultures. (EVR); **Below**: An oven in D.R. Congo, built from and used to fire bricks made from clay-rich soil extracted from an adjacent termite mound (partially excavated in the background). Finished bricks are stacked in the foreground. (EVR)



Soil health

The underlying principles of "soil health" are that soil is not just a growing medium, rather it is a living, dynamic and ever-so-subtely changing environment. Analagous to human health, a healthy soil can be considered as :

- being in a balanced state of well-being in terms of biological, chemical and physical properties;
- not being diseased (i.e. not degraded, nor degrading), nor causing negative off-site impacts;
- functioning interactively with each of its qualities to reach its full potential and resist degradation;
- providing a full range of functions (especially nutrient, carbon and water cycling) and in such a way that it maintains this capacity into the future.

The term soil health is used to express the ability of a soil to:

- sustain plant and animal productivity and diversity;
- maintain or enhance water and air quality;
- support human health and habitation.

Different soils have different levels of health conditions depending on the inherited qualities and on the environmental settings. Soil health can be measured in terms of individual ecosystem services provided relative to a particular site. Specific aspects used to evaluate soil health include CO_2 release, humus levels, microbial activity and available calcium.

Factors adversely affecting soil health include issues such as deforestation, absence of soil cover, overgrazing, monocropping, inappropriate tillage, soil nutrient mining and pollution.

Good practices to maintain and/or improve soil health include permanent soil cover (conservation agriculture), integrated plant - animal production, crop rotation/association, controlled grazing, controlled carbon levels (relatively close to the limits set by soil type and climate), integrated nutrient management, maintenance of biological productivity (relatively close to the limits set by the soil environment), contour tillage and terracing to reduce erosion and a limitation/reduction on the level of contaminants.

A small banana farm in Cameroon with underplanting of secondary crops that benefit both the soil and the local community - an example of good practices for sustaining soil health. Such land management practices reduce soil degradation rates, increase the accumulation of soil carbon, maintain soil moisture, improve soil structure and provide a better habitat for the soil microorganisms. Healthy soils provide better environmental services, and benefit both agricultural and ecological systems. Other examples include the Konso controlled grazing system in Ethiopia, traditional integrated agro-ecosystem management in hilly areas of Kenya and the land protection system in Burkina Faso. (EM)

Soil assessment – Land evaluation

Land evaluation

Decisions on land use have always been part of the evolution of human society. In the past, land use changes often came about by gradual evolution, as the result of many separate decisions taken by individuals. In the more crowded and complex world of today, the use of the land is frequently dictated by government policies or economic factors. In Africa, many land use changes are concerned with putting environmental resources to new kinds of productive use or for developing previously unused (often marginal) lands. To ensure the suitability of any proposed change, there is a need for an effective and holistic evaluation or assessment process. Such actions are particularly important in the context of current debates on the competition between biofuel and food crops or with nations acquiring land outside of their borders to assure food security or stable food prices.

The goal of land evaluation is to guide rational decisions on land use in such a way that the natural resources are put to the most beneficial use for man, while at the same time conserving those fundamental ecosystem functions for the future. Such evaluations must be based on a good understanding of both the natural environment and of the type of land use envisaged. There have been many examples of damage to natural resources and of unsuccessful land use enterprises through a failure to account for the mutual relationships between land and the uses to which it is put. Land evaluation should bring about such an understanding and present planners with options regarding the most promising kinds of land use.

An important consideration is that land evaluation is concerned with an assessment of land performance for a specified purpose. For example, the suitability for a crop such as cassava can be quite different to that for potatoes. The Food and Agriculture Organization of the United Nations (FAO) has developed a Framework for Land Evaluation which has been widely used throughout Africa [53]. The FAO approach involves understanding and interpreting the interactions between climate, soils, vegetation, topography and land use. To be of value in planning, land use considerations must be limited to those which are relevant within the physical, economic and social context of the area considered.

Soil characteristics and qualities in land evaluation

When land is mapped for resource exploitation, the areal units defined by the surveyor are normally described in terms of land characteristics (i.e. an attribute that can be measured or estimated). Examples include slope angle, rainfall, soil texture, available water capacity and biomass of the vegetation.

If land characteristics are employed directly in an evaluation, problems can arise from the interaction between characteristics. For example, the hazard of soil erosion is determined not only by the angle of the slope but also by its length, vegetation cover, soil structure, rainfall intensity and other characteristics. Because of these interactions, it is recommended that the comparison of land with land use should be carried out in terms of composite indicators of land qualities.

In this context, a land quality indicator is a complex attribute of land which acts in a distinct manner in its influence on the suitability of land for a specific kind of use. Land qualities may be expressed in a positive or negative way. Examples include moisture availability, erosion resistance, flooding hazard, nutritional value of pastures and accessibility. Where data are available, aggregate land qualities may also be employed (e.g. crop yields, mean annual increments of timber species).

The soil assessment part of such an approach involves transforming soil characteristics into soil quality indicators before matching them with crop requirements.

Soil qualities and related soil characteristics

Soil qualities are related to the agricultural use of the soil and more specifically to specific crop requirements and tolerances. To illustrate the relationship, the following table outlines the soil characteristics needed to define the seven soil quality indices that are required to define land suitability for maize cultivation.

Soil qualities		Soil characteristics
SQ1	Nutrient availability	Soil texture, soil organic carbon, soil pH, total exchangeable bases
SQ2	Nutrient retention capacity	Soil organic carbon, soil texture, base saturation, cation exchange capacity of soil and of clay fraction
SQ3	Rooting conditions	Soil textures, bulk density, coarse fragments, vertic soil properties and soil phases affecting root penetration and soil depth and soil volume
SQ4	Oxygen availability to roots	Soil drainage and soil phases affecting soil drainage
SQ5	Excess salts	Soil salinity, soil sodicity and soil phases influencing salt conditions
SQ6	Toxicity	Calcium carbonate and gypsum
SQ7	Workability (constraining field management)	Soil texture, effective soil depth/ volume, and soil phases constraining soil management (soil depth, rock outcrop, stoniness, gravel/ concretions and hardpans)

Assessing the suitability for maize cultivation in Africa

The following text describes a typical land evaluation exercise to assess the suitability of maize cultivation. Seven key soil qualities have been identified as being critical for maize production: nutrient availability, nutrient retention capacity, rooting conditions, oxygen availability to roots, excess salts, toxicities, and workability.

- Nutrient availability (SQ1)

This soil quality is decisive for successful low level and intermediate input farming. Therefore, diagnostics related to nutrient availability are manifold. Important soil characteristics of the topsoil (0-30 cm) are: soil texture, structure, organic carbon, pH and total exchangeable bases (TEB). For the subsoil (30-100 cm), the most important characteristics are: texture, structure, pH and TEB.

- Nutrient retention capacity (SQ2)

Nutrient retention capacity is of particular importance for the effectiveness of fertiliser applications and is therefore of special relevance for intermediate and high input level cropping conditions. Nutrient retention capacity refers to the capacity of the soil to retain added nutrients against losses caused by leaching. Plant nutrients are held in the soil on the exchange sites provided by the clay fraction, organic matter and the clay-humus complex. Losses vary with the intensity of leaching which is determined by the rate of drainage of soil moisture through the soil profile. Soil texture affects nutrient retention capacity in two ways, through its effects on available exchange sites on the clay minerals and by soil permeability.

The soil characteristics used for topsoil are organic carbon, texture, base saturation, cation exchange capacity of soil, pH and cation exchange capacity of the clay fraction. Soil pH serves as an indicator for aluminium toxicity and for micro-nutrient deficiencies.

- Rooting conditions (SQ3)

Rooting conditions address various relationships between soil conditions of the rooting zone and crop growth. They include effective soil depth (cm) and effective soil volume (vol. %) and are related to the presence of factors that restrict the effective rooting depth or decreases the effective volume of soil that is accessible to roots. As soil depth/volume limitations affect root penetration and may constrain yield formation (roots and tubers), the following factors are considered in the evaluation:

1. adequacy of foothold (i.e. sufficient soil depth for anchoring the crop);
2. available soil volume and penetrability of the soil for roots to extract nutrients;
3. space for root and tuber crops for expansion and economic yield in the soil; and
4. absence of shrinking and swelling properties affecting root and tuber crops.

Relevant soil properties to be considered are soil depth, soil texture/structure, the presence of swelling clays, soil temperature and the presence of coarse fragments (stones) or surface crusts.

- Oxygen availability (SQ4)

Oxygen availability in soils is largely defined by the drainage characteristics of soils. The determination of soil drainage classes is based on soil type, soil texture, slope, movement of the groundwater table and the occurrence of waterlogging, periodic flooding or iron pans in the soil.

- Excess salts (SQ5)

Accumulation of salts may cause salinity. An excess of free salts (soil salinity) is measured as electric conductivity (in dS/m) or as saturation of the exchange complex with sodium ions, which is referred to as sodicity or sodium alkalinity and is measured as exchangeable sodium percentage (ESP).

Salinity affects crops by inhibiting the uptake of water. Moderate salinity affects growth and reduces yields; high salinity levels may kill the crop. Sodicity causes sodium toxicity and affects soil structure leading to a massive or coarse columnar structure with low permeability.

- Toxicities (SQ6)

Low pH leads to acidity related toxicities (e.g. aluminium, iron, manganese toxicities) and deficiencies (e.g. phosphorus, molybdenum). Conversely, calcareous soils generally exhibit micronutrient deficiencies of iron, manganese and zinc and in some cases toxicity of molybdenum. Gypsum strongly limits available soil moisture. Tolerance of crops to calcium carbonate and gypsum varies widely.

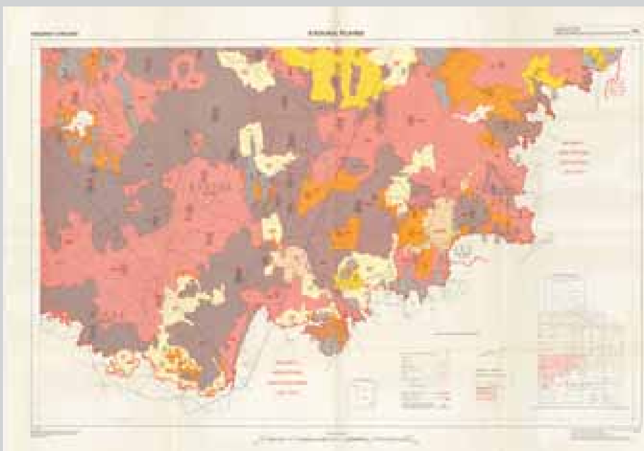
Low pH and high calcium carbonate and gypsum levels are mutually exclusive. Acidity related toxicities such as aluminium toxicities and micro-nutrient deficiencies are accounted for respectively in SQ1 and in SQ2. Therefore, this indicator only includes calcium carbonate and gypsum related toxicities.

The Land Systems Approach

One challenge facing early natural resource surveys was the physical size of the areas being considered. Methods were sought to allow a rapid appraisal of land in order to identify areas of promise for future developments. What became known as the Land Systems approach emerged from the early use of black and white aerial photography by the Division of Land Use in Australia, the National Institute of Road Research in South Africa and MEXE, an experimental unit of the British Army.

The Land Systems approach was particularly suited to multi-disciplinary teams investigating a broad range of landscape facets. Separate land systems were defined where recurring patterns of uniform environmental conditions were identified: therefore, a land system could be expected to have broadly similar topographic, soil-based, vegetative and climatic, conditions. These distinctions were kept at a high level and so were appropriate for delineation from aerial photography, thus providing a flexible framework for rapid field survey. The Land Systems approach was then utilised for a range of high level applications, such as the provision of crop options for maize, millet, sorghum, groundnut, cotton, yam and rain fed rice. [54,54a]

The Land Systems approach was used worldwide, and especially in Africa. The WOSSAC archive in the UK (see page 139) holds a range of examples of Land System maps.



An example of a Land Systems map for the Kaduna Plains in Nigeria from 1978, itself part of a wider Central Nigerian project (CNP) undertaken by the British Land Resources Division of the Overseas Development Administration. This mapping included six northern states of Nigeria: numbered land systems were recorded based on assessment of landscape elements including geology, landform, relief, slope, drainage, outcrops, ironpan presence, soil and vegetative cover. (WOSSAC)

http://www.wossac.com/search/wossac_detail.cfm?ID=250

- Workability (SQ7)

Workability or ease of tillage depends on several interrelated soil characteristics such as texture, structure, organic matter content, soil consistency/bulk density, the occurrence of gravel or stones in the profile or at the soil surface and the presence of rock outcrops or continuous hard rock at shallow depth. Some soils are easy to work independently of moisture conditions, other soils are only manageable at an adequate moisture status, especially for manual cultivation or light machinery. Constraints related to soil texture and structure affect low and intermediate input farming systems, while the constraints related to irregular soil depth, volume of stones and irregular soil depth affect mechanised land preparation and harvesting operations. Workability constraints are therefore handled differently for low/intermediate and high input agricultural systems.

The workability soil quality includes physical hindrance to cultivation and limitations to cultivation imposed by texture/clay mineralogy.

Agro-ecological zoning and land evaluation for maize cultivation

In order to make an inventory and evaluate the biophysical land resource, the FAO has developed the system of agro-ecological zones (AEZ) [55, 55a, 55b]. The FAO-AEZ classification is based on key characteristics of the climate, soils and topography. For climate, the number of days during the year that rain-fed soil moisture is available when temperature conditions allow crop growth is calculated. This period is referred to as the reference length of growing period (LGP) and is derived from a water balance model (see page 17). For this exercise, the soil quality indices described above were calculated from the Harmonized World Soil Database (HWSD - see page 136) while the topography and slope information were derived from the SRTM database (see page 15).

- Climate classes

  Desert/Arid: <60 days LGP

  Dry semi-arid: 60-120 days LGP

  Moist semi-arid: 120-180 days LGP

  Sub-humid: 180-270 days LGP

  Humid: >270 days LGP

- Soil classes (HWSD FAO' 90)

  Hydromorphic soils: Gleysols, Histosols, gleyic units

  Excellent soils: Cambisols, Luvisols, Nitisols, Chernozems, Kastanozems, Phaeozems, Greyzems, Fluvisols (>2% slope).

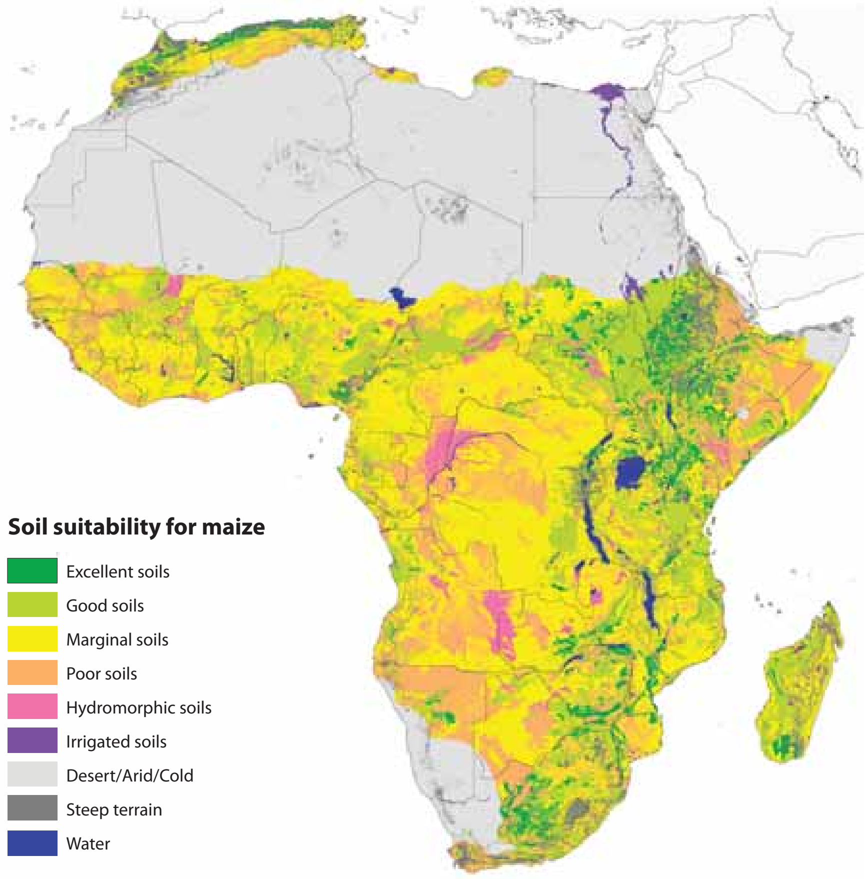
  Good soils: Vertisols, Regosols, Andosols, Podzoluvisols.

  Marginal soils: Ferralsols, Arenosols, Lixisols, Podzols, Plinthosols, Planosols, Acrisols, Gleysols, Arenosols, Podzols (>2% slope).

  Poor soils: Alisols, Calcisols, Gypsisols, Solonchaks, Solonetz, Leptosols, Histosols, Anthrosols (>2% slope), miscellaneous units, Soils with lithic, stony, petrocalcic, petroferric or petrogypsic, saline, sodic, rudic, salic, takyric and yermic phases.

Calculation of land suitability index

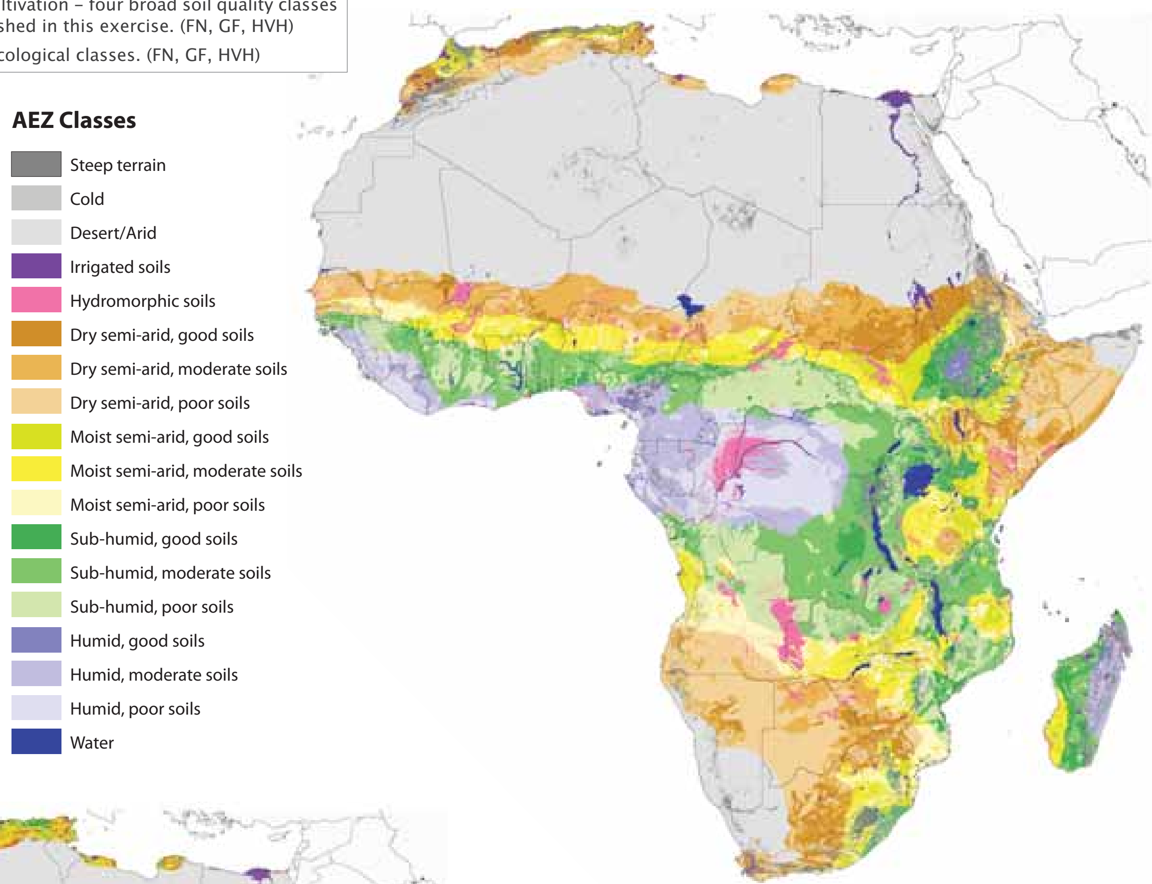
The specific requirements for maize production were compared against the agro-ecological parameters for each cell in the AEZ map. Land was scored as being very suitable, suitable, marginally suitable and not suitable. The final output map (on the right) clearly defines the most suitable regions in Africa for maize cultivation. It is important to note that this is not a map of actual production and that less suitable areas could become suitable on the basis of changes in land management practices, the introduction of farming technologies and climate change. In fact, one of the strengths of this approach is that by varying parameters such as soil moisture and length of the growing season, the impact of climate change on the distribution of specific crops can be assessed. Such outputs are vital in discussions on food security.

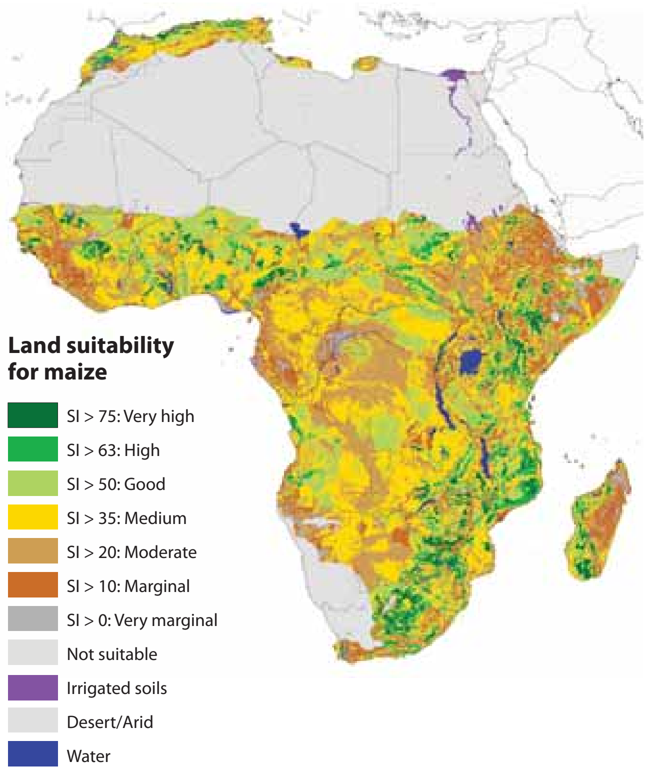


Young maize or corn (*Zea mays*) plants. Maize is Africa's primary source of food. Leafy stalks produce ears which contain seeds or kernels that are used as a vegetable or starch in cooking or animal feed. (AJ)

Above: Map showing soil suitability classes for low input maize cultivation – four broad soil quality classes were distinguished in this exercise. (FN, GF, HVH)

Right: Agro-ecological classes. (FN, GF, HVH)





Land suitability map for maize in Africa at low input. It is clear that large parts of Africa are unsuited to this type of agriculture. Optimum cultivation is predominantly in south-eastern Africa, in parts of the Sahel and on the more humid regions of the North Africa. (FN, GF, HVH)

The East African Groundnut scheme

A fundamental experience which contributed to the use of soil and land evaluation surveys was the failure in the late 1940s of the ambitious East African Groundnut* Scheme (see Ferralsols section on page 53). This embarrassing experience, in what was then Tanganyika, failed to produce any meaningful quantities of groundnuts and was to influence the planning of all subsequent commercial agricultural schemes in Africa [56].

Sites considered to be suitable for groundnuts were identified in 1946. But problems such as unreliable rainfall and, most importantly, the largely infertile and stony soils which were difficult to cultivate with machinery, led to the collapse of this ambitious endeavour in 1949. The failure of this scheme initiated the requirement for rigorous land assessments before embarking on any future agricultural scheme into the thinking of development planners and boosted the status of soil surveys and land evaluation in the decades that followed.

*Despite its name, the peanut (or groundnut - *Arachis hypogaea*), is actually a legume (i.e. a bean). Peanuts grow best in light, sandy loam soil and require five months of warm weather together with an annual rainfall of 500-1 000 mm (or the equivalent in irrigation).

A Planosol from Morocco. The sharp boundary between the light, silty topsoil (above 40 cm) and the darker, clayey subsoil (below 40 cm) is clearly evident. This change in texture is a relict of past sedimentation processes. (EM)

A young soil around 40 cm deep showing only limited evidence of soil-forming processes. The soil body is very stony. The underlying bedrock is being weathered into large blocks. To the right of the tape, exfoliation (also known as onion skin weathering) is causing the rock to detach along concentric planes. (EM)

A Vertisol from North Africa. This heavy, clay-rich soil is very productive when cultivated. However, the presence of swelling clay minerals make the soil sticky when wet and hard when dry. Deep cracks (up to 1 m in length in the photograph) and a lack of clearly defined horizons are characteristic of this soil type. (EM)

Kaolinite clay occurs in abundance in soils that have formed from the chemical weathering of rocks in hot, moist climates, for example in tropical rainforest areas. Comparing soils along a gradient towards progressively cooler or drier climates, the proportion of kaolinite decreases, while the proportion of other clay minerals such as illite (in cooler climates) or smectite (in drier climates) increases. Such climate-related differences in clay mineral content are often used to infer changes in climates in the geological past, where ancient soils have been buried and preserved. This profile is from Kenya. (EM)

Soil Classification: Naming and grouping soils together

From the previous pages of this atlas, one can understand how soil can develop different characteristics with depth and in different geographical areas. Apart from glaciers, water and urban areas, soil covers the Earth's surface as a continuum (even bare rock surfaces can have soil material at microscopic level). The gradual changes of soil characteristics across the landscape make the comparison of different soil types difficult. In addition, soil is highly complex, much more so than water or air, and lacks the hierarchical order of many biological systems (e.g. orders, families, genera or singular: genus). To overcome this problem pedologists (scientists who study soil) have developed various ways to characterise, identify, label and group soil bodies according to certain rules. This important task is known as soil classification, one of the advanced branches of basic and applied soil sciences.

Classification is the procedure by which soil is arranged into groups, categories or, as the word implies, classes, relevant to a specific purpose. The purpose of any classification is to organise our knowledge in such a manner that the properties of objects may be remembered and their relationships may be understood most easily for a specific objective. The process involves formation of classes by grouping the objects on the basis of their common properties. Classification helps us deal with complexity. There are too many objects to consider individually. If we can find some common properties or behaviour between them, we can make meaningful classes to help us organise our knowledge and simplify our decision making.

Early soil classifications were based on individual characteristics such as the texture of the topsoil (e.g. loam, clay or sand) or the parent material (e.g. alluvial soil, gravelly soil, etc.). During the late 1880s, the Russian geologist Dokuchaev, now regarded as the father of soil science, was the first to suggest a more scientific classification based on the combination of soil characteristics in relation to their formation. This approach, known as the genetic principle, remains the guide for most present day national soil classification. This principle allows features resulting from soil-forming processes to be distinguished from those whose origin is geological.

Different approaches to soil classification

During the twentieth century many new soil classification systems were developed around the world as a result of a growing interest in soil conservation and alternative land uses from agriculture. These systems focused on various basic and applied aspects which could be grouped into two categories: natural and technical.

Natural classifications group soil types by some intrinsic properties, behaviour, or origin without reference to any particular use. Examples include:

- Group by ecologically important characteristics such as soils of savannah or tropical rainforest. Such groups may be geographically-compact but can have diverse properties and functions;
- Group by origin where a common development, depending on the interpretation of soil-forming factors and soil genesis, is presumed. This type of classification is called genetic. The soil is considered as a natural body with its own history and ecology.

Technical classifications group soil types by some properties or functions that relate directly to a proposed purpose. Examples include:

- Hydrological: groups soil types according to water regimes such as drainage classes;
- Agricultural suitability: groups soil types according to their ability to support specific crops or agricultural activities;
- Land use capability: groups soil types according to their land management capacities;
- Fertility: groups soil types according to the availability of essential nutrients;
- Engineering: groups soil types according to their bearing strength and behaviour under different moisture conditions.

Soil science, unlike many other scientific disciplines (e.g. botany), does not have a single, universally used, classification system (see text on current trends below). This is because soil is far too complex for a single classification to be applicable globally. Therefore, many countries have developed their own specific approaches to classifying soils based on national concepts or practical needs, often using local names for soil types based on the identification of typical examples. This approach complicates the comparison of soil types between different parts of the world as names often do not translate well between taxonomic systems. The FAO Legend for the Soil Map of the World was an attempt to address the need for a globally accepted soil classification system. While several countries have used the FAO legend for national mapping purposes, many difficulties were encountered.

Current trends

A number of soil classification systems have developed that use quantitative criteria involving field assessed soil characteristics and/ or laboratory analysis to identify and refine hierarchical classes. Such approaches have been used in many countries to revise national classification schemes. The availability of quantitative soil parameters eases the comparison of national classification systems because specific characteristics can be examined rather than broad concepts.

Revision of the United States Department of Agriculture's (USDA) Soil Taxonomy classification scheme [57] and the development of the World Reference Base for Soil Resources (pages 48-59) from the FAO Legend of the Soil Map of the World were important responses to this more analytical approach.

In 1998, the 16th Congress of the International Union of Soil Science in Montpellier, France, adopted the World Reference Base for Soil Resources as the official terminology to name and classify soils - the system used in this publication.

Towards a Universal Soil Classification System?

Most national soil classification systems were developed for a specific purpose, often quite different from the questions being posed today. Soils suitable for agricultural purposes, especially cultivation, usually received more attention in the past. In addition, national conditions often gave rise to particular perspectives and where the broad or global view of soils was normally not considered. This often led to massive confusion and disagreements between soil scientists. However, the current broader view of soil functions and understanding the role of soil in global environmental processes require a better understanding and description of all soils (in particular, anthropogenic soil, cold soils, soils of the tropical regions). In addition, most classification schemes were elaborated before the recent boom of observation technologies, data storage and computer processing capability.

At a meeting in Godollo (Hungary) in 2009 to celebrate the 100th anniversary of the 1st International Conference of Agrogeology (widely regarded as the first ever international soil science conference), participants called on the International Union of Soil Sciences (IUSS) to address the problem of our lack of a common language within the soil science community, particularly in relation to the taxonomy of soils.

Consequently, during the 2010 World Congress of Soil Sciences in Brisbane, Australia, the IUSS Council unanimously accepted the "Godollo Resolution" and established a Working Group to coordinate investigations and development of common standards, methods and terminology in soil observations and investigations towards a new universal soil classification system. In this context, the term 'universal' implies that a system is commonly accepted and commonly applicable.

Further details on the development of the Universal Soil Classification System can be found at the USDA Natural Resources Conservation Service web site through the following link:

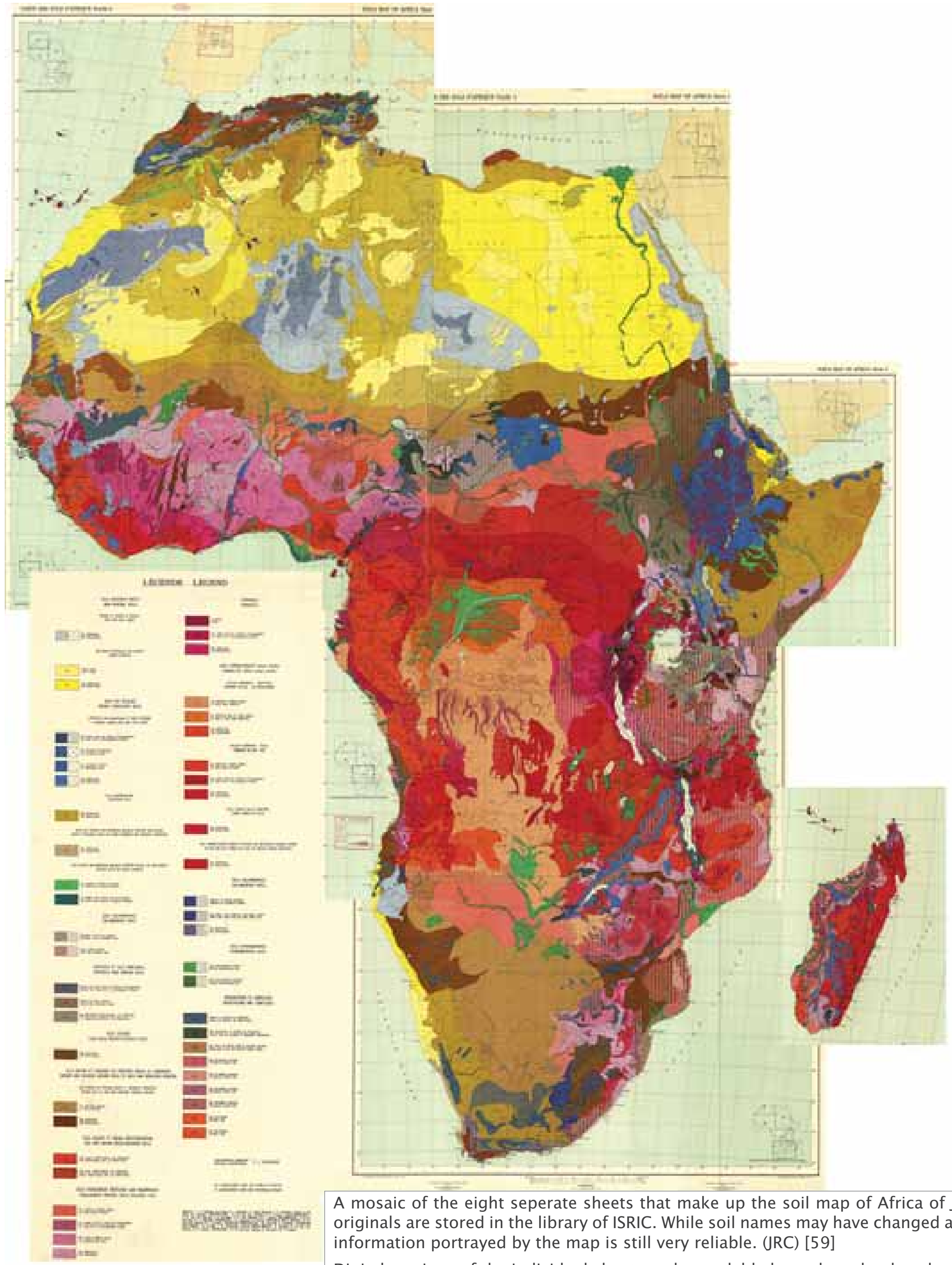
http://soils.usda.gov/technical/classification/Univ_Soil_Classification_System/

The pictures below show the variability of soil. The upper pair of images show characteristic red tropical soils from Ghana and Kenya. Despite the huge distance between their locations, they display similar characteristics and responses which would imply that they should be grouped together. The lower pair of images show a thin soil developing over hard bedrock (**lower left**) and a soil developing in a vegetated sand dune. Both are immature or young soils in a desert environment. However, the nature of their parent material and the amount of organic matter puts these two soils into separate classes. **Clockwise from below**: Acrisol, Ghana; Nitisol, Kenya; Arenosol, Morocco; Leptosol, Namibia. (EM)

Development of soil classification in Africa

"Soil is the source of all life. Yet we know more about soils of Mars than about soils of Africa."

Pedro Sanchez, Director of the Earth Institute's Tropical Agriculture and the Rural Environment Program (2010)



A mosaic of the eight seperate sheets that make up the soil map of Africa of Jules D'Hoore (1963-1964). The originals are stored in the library of ISRIC. While soil names may have changed and boundaries refined, the basic information portrayed by the map is still very reliable. (JRC) [59]

Digital versions of the individual sheets and a readable legend can be downloaded from the EUDASM archive: http://eusoils.jrc.ec.europa.eu/esdb_archive/eudasm/africa/

At the end of the 19th century and during the first half of the 20th century, the soils of Africa were investigated by European soil scientists according to their understanding of temperate soils at that moment. At this time, the Dokuchaev principle of zonality, associating the location and characteristics of soils with climate and vegetation zones, still played an important role in soil classification and mapping. In the early 1890s, studies in South Africa grouped soils according to the zonality concept. This was reinforced by the presence of large tracts of uniform soil, such as the red Kalahari sands, the black clays and the highly weathered soils of the eastern escarpment. In 1900, a very important soil survey was concluded by French colonial institutions in Madagascar which collected 500 soil samples on the "red island" to be analysed in Paris. Information on ochrous or red earths, yellow earths, purplish earths and sandy earths, together with an agricultural map of the island, were presented at the international exposition in Paris in 1900.

Even in these very early studies, the red soils of Africa were considered to be special. Several surveys noted the occurrence of such soils, as is shown in the use of the term 'Red Earths' in early British literature. After the identification of laterites in India in 1807, the red soils of Africa became equated with laterites and the term Lateritic soil became popular probably leading to the early misconception that all red soils are laterites (see page 26). Lateritic soils were observed in Madagascar in 1902.

However, the zonal soil concept that so influenced classifications in Russia and America did not conform to the ancient land surfaces of Africa as the continent has been subjected to considerable climatic fluctuations. Some of the old stable landscapes on which soils were formed date back to the mid-Tertiary period. Although weathering crusts were not scraped away by glaciers and ice caps as they were in Europe and North America, Africa underwent several pluvial (wet climate) and inter-pluvial cycles of erosion and sedimentation. Stone-layers in strongly weathered soils are generally the result of geological erosion and deposition and suggest that the soils are formed on transported deposits. Hence, strongly weathered and deep regoliths are the products of successive geomorphological cycles and are the result of geogenesis rather than pedogenesis.

The development of soil classification systems has gone on hand in hand with developments in survey methodology. In 1904 the soil series was introduced by the US Soil Survey as a basic mapping unit. The series originally included all soil types developed on the same parent material, but the concept changed from being a geological unit to a mainly climatically-developed unit, and ultimately, to an independent natural unit defined on the basis of its own properties. The present concept of the soil series is of soils that are essentially alike in all major profile characteristics. This concept has been adopted for soil mapping in most parts of Africa.

The earliest known soil map of Africa at a scale 1:25 million was published by C.F. Marbut in 1923 [58]. This map is based on the analyses of less than thirty soil profiles scattered over the entire continent. The intention was to show the probable location and trend of the great soil belts of Africa based on climatic, lithological or phytogeographical factors. Between 1930-1945, this map was supplemented by several notable small-scale surveys undertaken on limited budgets and with few staff (e.g. Z.Y. Shokalskaya in 1944). Of note were a reconnaissance survey of the Belgian Congo and a map of the central part of Nyasaland (Malawi).

The Provisional Soil Map of East Africa by G. Milne (1935-1936), developed using the concept of the soil catena, is regarded by many as the outstanding survey of this period (see page 15). The value of the catena concept to soil survey is that it permits the prediction of soil distribution based on landscape position. This is particularly useful in reconnaissance surveys where the extrapolation of repeating landscape units over large areas is required. An ecological approach to soil mapping was adopted for Northern Rhodesia (1937, 1943, 1948) which exploited the relationship between vegetation and associated soils. In Rhodesia a soil classification based on geological materials was proposed at the end of the 1940s, because of the marked differences in soils that were associated with changes in parent material. A descriptive legend based on this system, including references to mean annual rainfall, temperature, altitude, and the dominant vegetation, was subsequently used for the Provisional Soil Map of Southern Rhodesia (Zimbabwe).

The term "Podzolic" made its first appearance in 1938 with regard to soils of tropical regions on account of the occurrence of light coloured surface horizons linked to a subsurface accumulation of clay. With the introduction of the concept of Podzolic soils, many of the red soils were moved into this group as the textural change began to be considered to be more significant than the colour. The different meanings given to the terms Laterite, Lateritic and Podzolic resulted in a high degree of confusion regarding the classification of tropical and sub-tropical soils.

After 1945 there was a growing demand for a comprehensive soil taxonomy that would help evaluate soils in developing countries, especially with regard to their potential for food production. A resurgence of soil studies in the tropics saw the emergence of new terms. In 1947, the term Latosol was introduced to bring together some of the highly weathered soils. Many kinds of Latosols were soon recognised, differentiated by the reddish-yellow, red or dark red colour of the B horizon. The 1950s saw an increase in the number of studies on African soils as a result of European countries, especially Belgium, France and Portugal, establishing a pedological section within large research stations in their African colonies. The increased interest in soil survey resulted automatically in a special interest in soil classification. One of the early problems was the confusion created by the use of the term 'Laterite', covering a red soil, a red material that hardens or a hard iron-rich material. On the basis of an exploratory study in the Congo, the term 'Lateritic soils' was replaced at first by a more narrowly defined 'Latosol', characterised by a high degree of aggregate stability and a dominance of low activity clays and oxides of iron and aluminium. During this period, the term 'Ferralitic soils' appeared in French (1954) and Portuguese (1954) literature to group some of the red soils.

In 1954, the 5th International Congress of Soil Science was held in Leopoldville (Kinshasa), the first to be held in a tropical environment. The classification of soils in the tropics was amply discussed with special attention given to the use of the term 'Ferrallitic soils' as a substitute for 'Lateritic soils'. The name 'Latosol' was felt to be less suitable on account of its very broad scope and its reminiscence of the term 'Laterite'. At the 6th International Congress in Paris in 1956, a French system of soil classification was presented in which the red soils of the humid tropics were labelled as 'Sols Ferrallitiques' and 'Sols Ferrugineux Tropicaux'. In 1958 the terms Oxysols and Ochrasols were used in West Africa.

In 1960 the US Soil Survey produced the first operational version of Soil Taxonomy (see page 47) which brought a new impetus to soil classification. The new system attracted much international interest among less developed countries, which were often not in a position to assess its merits.

In order to ensure a more precise definition and a subdivision of the Latosols in the Congo, the term 'Kaolisols' was coined in 1961 to denote inter-tropical soils with the dominance of kaolinite in the clay fraction mixed with important quantities of free oxides. Kaolisols included Ferralsols and Ferrisols. Much emphasis was laid by Belgian soil scientists on characteristics that were easily recognisable in the field (e.g. the presence of pseudosands in Ferralsols or shiny clay skins in Ferrisols). Many of these criteria were later incorporated in international classification systems, such as Soil Taxonomy (Oxisols) and WRB (Ferralsols), and in the FAO Legend (Ferralsols).

Within the English-speaking parts of tropical Africa, the approach used in Ghana and in parts of Nigeria is perhaps the best known. The Ghana system (1962) is a natural classification based on rainfall and parent material. Freely-drained soils in the humid zone were divided in to Latosols if derived from parent material of intermediate to felsic composition and Basisols that developed from basic parent materials. Other British Commonwealth territories used various *ad hoc* local classifications.

In the former Belgian Congo, the INEAC (Institut National de l'Etude Agronomique au Congo) system (1961) emphasised successive stages of weathering. The Portuguese developed a classification for deep, relatively well drained profiles through a 'sialitico - fersialitico – ferralitico' sequence. Soil colour was an important feature of many groupings. For the general soil map of Angola (1:1 million), such groupings were used as taxonomic units, with complexes of groupings as cartographic units. The French pedologists of ORSTOM (Office de la Recherche Scientifique et Technique d'Outre-Mer) were also involved in the development and revision of soil classification systems throughout former French colonies, especially in Algeria and Morocco. A revision of the Ferrallitic soil classification was published in 1966, followed by the first French classification. The ORSTOM system put much emphasis on climatic zonation rather than lithogenic influences. It is a natural, hierarchical system, based on the evolution of the profile as a whole.

Please read [52, 54a, 54b, 60] for further information on the history of soil survey in Africa.

Towards a common system

The establishment of national soil survey classifications resulted in a confusing situation as no one system was universally accepted. Two developments served as a basis for international exchange of pedological and agronomic information. They include the FAO 'Soil Map of the World (scale 1: 5 000 000) which started in 1961 and the Soil Map of Africa (also at a scale 1: 5 000 000 - see facing page) published in 1964 in the framework of a joint project by the Inter-African Pedological Service and the CCTA (Commission de Coopération Technique en Afrique) [59].

The CCTA classification reflected a major effort of correlation between the various systems in use in different African countries. It is an outstanding synthesis and was particularly valuable in bringing the ORSTOM and INEAC approaches to the attention of anglophone countries in Africa. This approach was used in a number of regions, including Northern Rhodesia (Zambia), Southern Rhodesia (Zimbabwe), Nyasaland (Malawi) and by the British Land Resources Development Centre. The development and application of this system stimulated cooperation and the international exchange of pedological information and ideas.

Although initially developed as a legend for a specific map and not a soil classification system per se, the FAO Legend (1974) found quick acceptance as an international soil correlation system [61]. It has been used on FAO soil surveys in Africa and as a basis for the national soil classification in many African countries (e.g. Kenya). The revised Legend (1988) introduced amendments based on experience gained while using the legend in Botswana, Egypt, Kenya, Sierra Leone and Zambia. The revised Legend was used as the basis for the national map of Botswana.

Through their National Soil Institutions, most countries have updated their soil information since the publication of the FAO Soil Map of the World. In fact, several African countries have now produced national soil maps that in scale and level of information can easily compete with those from the industrialised world. Botswana, Kenya, Rwanda, Ghana, Tunisia are but a few examples of countries that have gone to great lengths to carry out a full inventory of their soils.

In the 1960s, attempts were made in South Africa to apply Soil Taxonomy to South African conditions. Many of the principles, particularly the use of diagnostic horizons, were subsequently used in devising a new two-tier system that culminated in the publication of "Soil Classification: A Binomial System for South Africa" in 1977. A revised version, "Soil Classification: A Taxonomic System for South Africa", was published in 1991. A similar keyed classification of soil series was produced for Zambia in the 1980s but it is far more flexible, allowing for expansion and modification as experience grows and new series are defined.

Since 1982, the International Society of Soil Science had been active in the development of an internationally acceptable soil classification system. In 1992, the Working Group Reference Base (RB) proposed the FAO Revised Legend as a base, rather than developing a fully new soil classification system, and to give it more scientific depth and coherence. The first version of the World Reference Base (WRB) was endorsed in 1998, in a historical motion, as the official soil correlation system of the International Union of Soil Science (see page 50).

Indigenous soil classifications

For millennia, farmers in Africa have, through experience, developed a detailed nomenclature of different types of soils. This knowledge, accumulated over time, constitutes fundamental socio-cultural and economic values of each local community. For example, the old name of Egypt was Kemet, meaning alluvial dark and fertile soils and the word 'deshret' in ancient Egyptian was the name of desertic red soils.

Indigenous knowledge of soils was regarded by the scientific community as a simplistic collection of human experiences and primary attitude towards understanding natural resources. However, in the 1960s, scientists began to perceive the pertinence of indigenous soil knowledge on land development strategies. Understanding farmers' knowledge on soil and land management strategies appeared to be of utmost interest for developing improved technologies for sustainable soil fertility management at local level. For example, the local specificity and indigenous knowledge should be taken into account to ensure the successful implementation and adoption of new technologies.

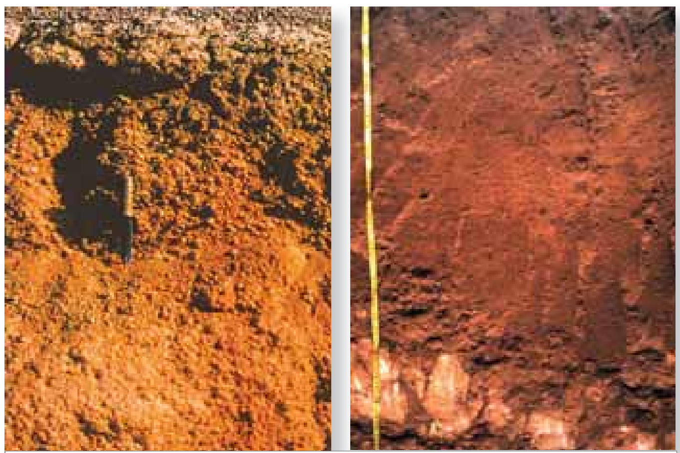
Nowadays, increasing interest in traditional soil knowledge has led to the development of ethnopedology, a hybrid discipline between natural sciences and social sciences. However, local perception of soil quality shows an interest in sociology because this denotes the relationship between farmers and the land. Moreover, the diversity of soil quality representations in a given area implies the diversity of production systems.

Ethnopedology studies in Africa have revealed that indigenous soil classifications are based primarily on soil productive capacity. The main factors controlling the taxonomy fall into two groups: (i) environmental factors such landform (topography), vegetation and fauna; and (ii) topsoil morphological properties such as colour, depth, texture, density, stoniness and water movement. Some derived secondary factors include land slope, soil workability, stickiness and hardness. Examples include:

- The topsoil colour reflects soil fertility level. Dark soils are considered more fertile than other colours (red, white, etc.);
- The soil texture gives information about soil workability and soil water retention capacity;
- "Bissiga" in Mooré language (Burkina Faso) means sandy soil, usually used for millet and vegetable crops;
- "Bolé" denotes clayey soils, suitable for sorghum and other crops that need more moisture. In terms of soil management, soils with coarse texture are easier to work with the hoe. They have a high infiltration rate but a low water holding capacity;
- The landform is used to locate soil in the topographic position in the landscape and to estimate the level of erosion risks based on the slope;
- In the Mooré language, the upper part of a slope is called "zegedga" which denotes where erosion risks are high;
- In the Yemba language (Dschang, west Cameroon), soils of well-drained plains, called "tsa'a pepeuo" are considered to be very fertile and are used for intensive agriculture. Poorly-drained soils of inland valleys, "tsa'a ngui", are only used for off-season crop production or grazing.

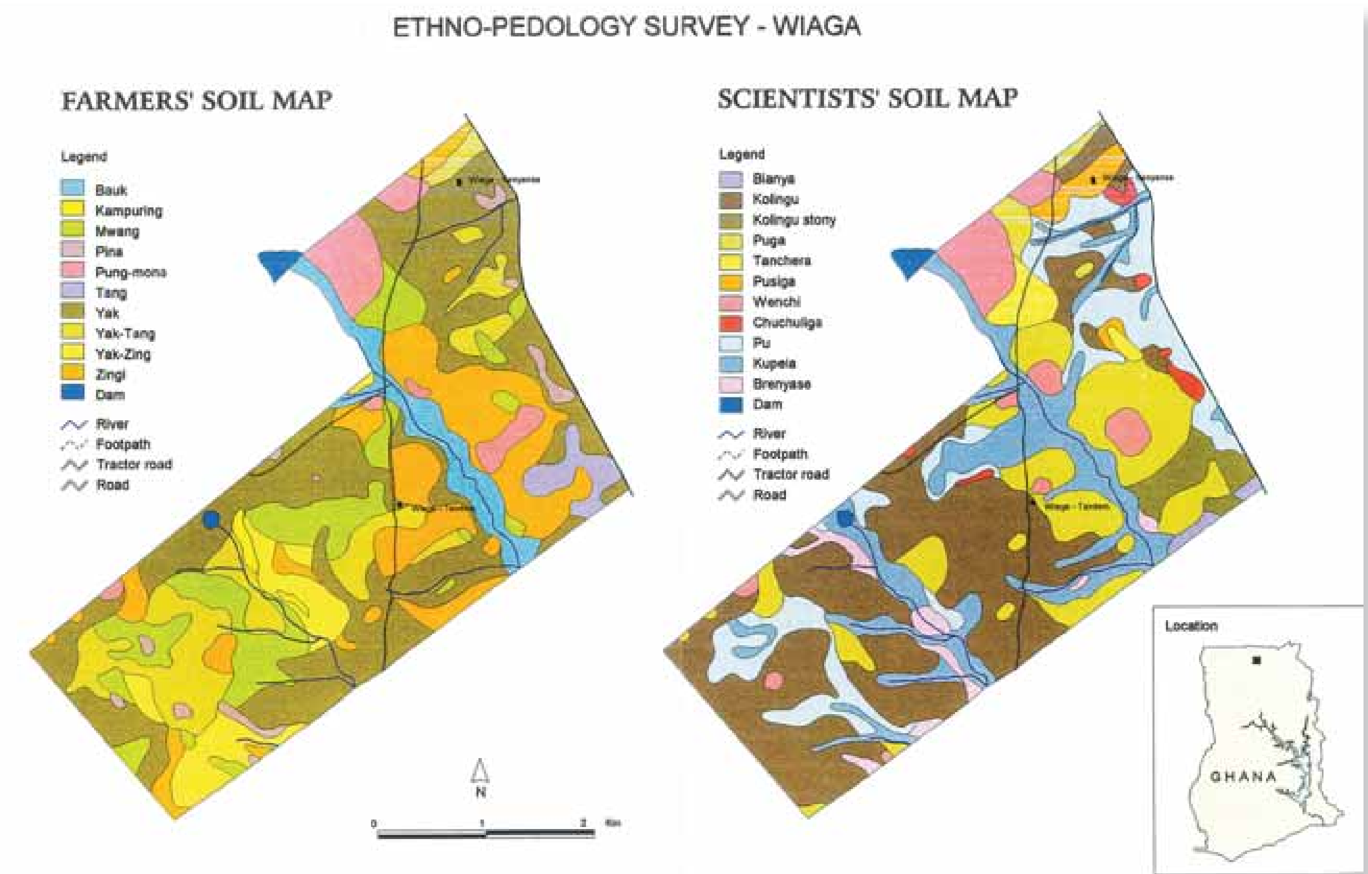
The vegetation can also be used to differentiate soils according to the original vegetation cover (forest soils, savannah soils). Plant species can also be used as soil fertility or infertility indicators.

Although these factors are used in most local soil classification, local management of soil fertility varies with individual capacities, local perception of constraints and other opportunities. Indigenous soil classification systems in Africa are increasingly being used by land managers and further research is needed to ensure better correlation of these indigenous systems and the conventional classification systems.



In the north east of Ghana, the Chromic Plinthic Lixisol on the **left** is known by the local Mamprusis people as *Kokua sabli*. These words denote the presence of iron–manganese nodules, the dark colour of the soil and a general low fertility, especially in drought conditions. The Chromic Lixisol on the **right** is known as *Bihigu sabli*, which denotes a dark colour and sandy textured soil found in the uplands. (both ISRIC) [62]

Local farmers tend to use their experience to evaluate and delineate soil types. They rely on topsoil colour and crop performance to assess nutrient levels, while texture is used to determine soil moisture relationships. (PDI)



A comparison between a soil map made by local farmers on the basis of their knowledge of local soil characteristics (left) and a more 'classically' produced map made by soil scientists (right). In some cases, there is a close correspondence while in other parts, there is a clear difference in diagnostic criteria. For example, in some areas farmers only consider texture as the basis for differentiation while soil surveyors consider physiography, drainage and depth. (ISRIC) [62]

The World Reference Base For Soil Resources

Origins

In the 1970s and '80s, the FAO and the United Nations Educational, Scientific and Cultural Organization (UNESCO) prepared a legend for the 1:5 million soil map of the world, broadly based on the main soil-forming factors. This map was used by many UN sponsored projects and, over time, many countries modified and adopted the legend to fit their particular needs [61]. Consequently, many of the soil units used in the FAO system are known in many countries and have similar meanings.

The World Reference Base for Soil Resources (WRB) was developed under the auspices of the International Union of Soil Science, by building on the foundations of the FAO legend, to create a common basis for correlating the soil resources of different countries [63]. Objective criteria derived from both field inspections and laboratory analysis of the soil are used to systematically classify different soil types into a Reference Group with specific characteristics denoted through the use of prefixes and suffixes (see page 51).

The WRB is not meant to replace national soil classification systems but rather designed to serve as a common language through which national soil classification systems can be compared and correlated.

The World Reference Base for Soil Resources

The WRB places all types of soil within thirty-two major soil groups (see adjacent column) with a series of uniquely defined qualifiers for specific soil characteristics (see page 51).

For describing and defining different types of soil, the WRB exploits the following nomenclature:

- soil characteristics comprising single observable or measured parameters;
- soil properties, a combination of characteristics indicating soil-forming processes;
- soil horizons, representing three-dimensional bodies characterised by one or more soil properties.

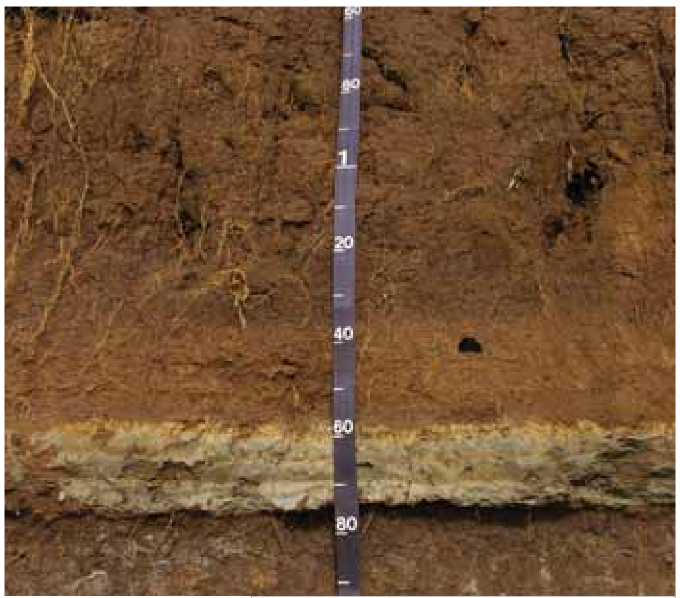
Soil horizons and properties are used to describe and define soil classes on the basis of 'diagnostic' criteria. This means reaching a certain degree of expression, as determined visually, by prominence, measurability, importance and relevance for soil formation, soil use and quantitative criteria. To be diagnostic, soil horizons also require a minimum thickness.

Reference soil groups in WRB are defined by the presence of diagnostic horizons. The soil in the picture has no diagnostic surface horizon. It has a bleached, light coloured albic horizon, from which the clay and some of the iron oxides have been translocated and accumulated in the underlying argic horizon. Below the argic horizon there is a red mottled horizon that cements upon drying to form a hard pan called plinthite. Because of the presence of the argic horizon and its low base saturation, the soil belongs to the Acrisols group. (EM)

WRB Reference Soil Groups

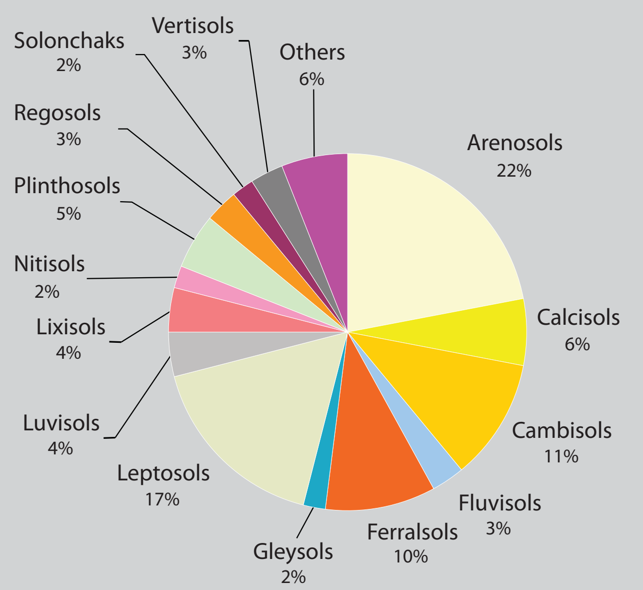
The thirty-two WRB Reference Soil Groups (RSG) are allocated on the basis of dominant identifiers which are usually the factors or processes that most clearly condition the formation of the soil. The sequence of the groups is according to the following principles:

1. Firstly, organic soil (**Histosols**) is defined to separate it from mineral soil.
2. The second major distinction is to recognise human activity as a soil-forming factor. Hence the position of the **Anthrosols** and **Technosols** after the **Histosols**; a benefit to the early definition of **Technosols** is the removal of soil that could be toxic and should not be touched.
3. Next are soil types with a severe limitation to rooting (**Cryosols** and **Leptosols**). **Cryosols** combine all mineral soil types that are affected by permafrost (a layer of soil that is continuously frozen for two or more consecutive years). **Leptosols** are mainly found in the mountainous areas and comprise shallow soils over hard rock and extremely stony soils with little fine earth.
4. Then comes a group of RSG that are or have been strongly influenced by water: **Vertisols**, **Fluvisols**, **Solonetz**, **Solonchaks** and **Gleysols**. **Vertisols** are churning, heavy clay soils with a high proportion of swelling clays. Deep and wide cracks form from the surface downward when they dry out and close when wet. **Fluvisols** occur in river valleys and comprise soil in recent alluvial, lacustrine or marine deposits and display a characteristic layering of sediments. **Solonchaks** have a high concentration of soluble salts at some time in the year and are largely confined to arid and semi-arid climate zones or coastal regions. **Solonetz** are strongly alkaline soils (pH > 8.5) and have a dense, strongly structured, clayey subsurface horizon that has a high proportion of adsorbed sodium and/or magnesium ions. **Gleysols** are soils with a high groundwater table. The distinctive oxidation-reduction pattern of brownish zones on the outer side of structural elements and along pores versus a grey, blue or green matrix, indicative of groundwater influence, set **Gleysols** apart from other wet soils.
5. The following group contains soils where iron (Fe) and/or aluminium (Al) chemistry plays a major role in their formation: **Andosols**, **Podzols**, **Plinthosols**, **Nitisols** and **Ferralsols** (the latter three are mostly found in the tropics). **Andosols** are soils developed in volcanic ejecta. They are characterised by a unique aluminium-silica chemistry as a result of rapid weathering of the volcanic minerals. **Podzols** have a typical ash-grey upper subsurface horizon, bleached by the loss of organic matter and iron oxides, on top of a dark accumulation horizon of humus and Fe compounds. Distribution in Africa is limited to temperate zones and small pockets in the tropics. **Plinthosols** contain plinthite, an iron-rich, humus-poor mixture of kaolinitic clay, quartz and other constituents that hardens irreversibly on exposure to repeated wetting and drying, **Nitisols** are deep, well-drained, red, tropical soils with diffuse horizon boundaries and a subsurface horizon containing shiny, flat-edged or nut-shaped polyhedric elements. **Ferralsols** are the classical deeply weathered, red or yellow soils of the humid tropics. They have diffuse horizon boundaries, and a high aluminium content.
6. Next comes a group of soil types with perched water: **Planosols** and **Stagnosols**. **Planosols** have a light-coloured, coarse-textured surface horizon that shows signs of periodic water stagnation and abruptly overlies a dense, slowly permeable subsoil with significantly more clay than the surface horizon. Found on flat lands, they are typically seasonally waterlogged. **Stagnosols** display a characteristic oxidation-reduction mottling pattern due to processes caused by periodically stagnating surface water.
7. The next grouping comprises soils that occur predominantly in dry grassland regions (e.g. savannahs) that have well developed humus-rich topsoils and a high base saturation: **Chernozems** have a thick, dark, humus-rich surface horizon. **Kastanozems**, found in drier conditions, also display a humus-rich surface horizon but it is thinner and not as dark as that of the **Chernozems**. Due to more humid conditions, **Phaeozems** are leached more intensively so that the dark, humus-rich surface horizon contains less bases.
8. The next group comprises soil from drier regions with accumulation of gypsum (**Gypsisols**), silica (**Durisols**) or calcium carbonate (**Calcisols**).
9. Then comes a group with a clay-rich or argic subsoil horizon. They can be grouped as having a) low base status, with high-activity clays (**Alisols**) or low-activity clay (**Acrisols**) or b) high base status, with high-activity clay (**Luvisols**) or low-activity clay (**Lixisols**). **Albeluvisols** (with tongues of topsoil protruding into the subsoil) are not found in Africa.
10. The last group contains relatively very homogenous sands and young soils that have limited or poor profile development: **Umbrisols**, **Arenosols**, **Cambisols** and **Regosols**. **Umbrisols** are associated mainly with acidic parent material and areas with an excess of precipitation. Under these conditions deep, dark-coloured and acid surface layers develop which are known as umbric horizons, from which the soil derives its name. **Arenosols** are undifferentiated soils in sandy deposits such as wind-blown sands of deserts. **Cambisols** have a subsurface horizon that only shows some initial development such as a change in colour and/or soil structure. **Regosols** comprise undifferentiated fine and medium textured soils.



A Fluvisol profile from Tanzania showing a characteristic layering of sediments. (EM)

WRB Reference Soil Groups in Africa



The chart shows the share of the major WRB Reference Soil Groups for Africa. Reference Groups occupying 1% or less have been combined as 'Other'. The total area comprises some 30 million km² or about 20% of the global soil cover. (AJ)

The continent of Africa contains all but one of the WRB Reference Soil Groups and illustrates a great soil diversity (see page 61). It is important to notice that over 60% of the soil types represent hot, arid or immature soil assemblages: Arenosols (22%), Leptosols (17%), Cambisols (11%), Calcisols (6%), Regosols (2%) and Solonchaks/Solonetz (2%). A further 20% or so are soils of a tropical or sub-tropical character: Ferralsols (10%), Plinthosols (5%), Lixisols (4%) and Nitisols (2%). A considerable area (6%) is occupied by a further 16 reference groups that cover an area of less that 1% of the African land mass. This fact illustrates that a considerable number of soil types are associated with local soil-forming factors such as volcanic activity, accumulations of gypsum or silica, waterlogging, etc. What is interesting is that unlike the other continents, Africa does not exhibit large expanses of prairie or steppe-type soils (i.e. Kastanozems, Chernozems and Phaeozems).

How to identify a soil according to the WRB?

Let's take a closer look at this soil profile from the delta of the Senegal River in northern Senegal.

The soil is this photograph (JD) clearly shows a structured surface layer, overlying a structureless subsoil. The layer between 20 and 40 cm depth shows some reddish-brown mottles and vague stratification on the right hand side of the photograph. Between 40 and 60 cm yellowish-orange spots are evident, indicative of the formation of the mineral jarosite (a basic hydrous sulphate of potassium and iron, characteristic of acid sulphate soil environments). Below 60 cm, the soil is uniformly grey in colour. The soil is clayey throughout and laboratory analysis indicates a pH of about 3 (very acid) in the jarosite layer.

The above combination of characteristics means that this soil classifies as a Fluvisol, which must exhibit Fluvic material starting within 25 cm of the soil surface or starting immediately below a plough layer of any depth and continuing to a depth of 50 cm or more. Moreover, the jarosite layer fulfils the criteria of a thionic horizon and the colour of the subsoil is indicative for a gleyic colour pattern and reducing conditions.

The next step is to identify the possible qualifiers for Fluvisols:

Prefix	Suffix
Subaquatic	Thionic
Tidalic	Anthric
Limnic	Gypsiric
Folic	Calcaric
Histic	Tephric
Technic	Petrogleyic
Salic	Gelic
Gleyic	Oxyaquic
Stagnic	Humic
Mollic	Sodic
Gypsic	Dystric
Calcic	Eutric
Umbric	Greyic
Haplic	Takyric
	Yermic
	Aridic
	Skeletic
	Arenic
	Siltic
	Clayic
	Drainic

Following the rules set by the WRB, the full name of the soil is an **Endogleyic Fluvisol** (**Hyperthionic**, **Clayic**). The specifier Endo- is added to Gleyic because the gleyic colour pattern starts below 50 cm. Hyper- is added to Thionic to indicate the very low pH.

WRB qualifiers

This section explains the terms used in the legend of the soil maps in this atlas. The description of the qualifiers below avoids technical language as much as possible to facilitate the reader's understanding of specific soil terminology.

Albic: a light-coloured subsurface horizon from which clay and free iron oxides have been removed, or in which the oxides have been segregated to the extent that the colour of the horizon is determined by the colour of the sand and silt particles rather than by coatings on these particles.

Arenic: having a loamy fine sand or coarser layer, at least 30 cm thick, within 100 cm of surface.

Argic: a subsurface horizon with distinctly higher clay content than the overlying horizon.

Brunic: having a layer starting within 50 cm of the soil surface, at least 15 cm thick, which meets certain alteration criteria of the cambic horizon but lacks the cambic texture criteria.

Calcaric: having 2% or more calcium carbonate between 20 and 50 cm depth.

Calcic: having a layer, 15 cm or more thick, with 15% or more secondary carbonate present only in the form of fine particles dispersed in the matrix or as discontinuous concentrations.

Cambic: having a subsurface horizon starting within 50 cm depth showing evidence of alteration with respect to the underlying material.

Carbic: having a layer with illuvial amorphous substances composed of organic matter and aluminium that does not become redder on ignition.

Chromic: having a reddish coloured subsurface layer, 30 cm or more thick.

Duric: a subsurface horizon showing weakly cemented nodules or concretions cemented by silica (SiO_2).

Dystric: having a base saturation of less than 50% in the major part between 20 and 100 cm depth.

Eutric: having a base saturation of 50% or more in the major part between 20 and 100 cm depth.

Ferralic: a horizon within 100 cm of the soil surface where the clay fraction is dominated by low-activity clays and the silt and sand fractions by highly resistant minerals, such as (hydr)oxides of Fe, Al, Mn and titanium (Ti).

Ferric: a horizon within 100 cm of the soil surface where segregation of Fe and/or Mn has taken place to such an extent that discrete nodules have formed and the internodular matrix is largely depleted of Fe.

Fibric: having, after rubbing, two-thirds or more of the organic material consisting of recognisable plant tissue within 100 cm depth.

Gleyic: having influence of groundwater within 50 cm depth.

Haplic: having no applicable other qualifier.

Hypoluvic: Having an increase in clay content of 3% or more within 100 cm of the soil surface (Arenosols only).

Lithic: having continuous rock within 10 cm depth.

Lixic: Having an argic horizon that has a low nutrient holding capacity in some part to a maximum depth of 50 cm below its upper limit.

Luvic: having a subsurface horizon with higher clay content than the overlying horizon, a moderate to high nutrient holding capacity and a base saturation of 50% or more between 50 and 100 cm depth.

Mesotrophic: having base saturation of <75% at a depth of 20 cm from soil surface.

Mollic: having a thick, dark surface horizon rich in humus and a neutral soil reaction.

Nudilithic: having continuous rock at the surface.

Pellic: having in the upper 30 cm of the soil a dark colour with a Munsell value when moist of 3.5 or less and a chroma of 1.5 or less (Vertisols only).

Petric: having a strongly cemented or indurated layer starting within 100 cm of the soil surface.

Pisoplinthic: having a horizon starting within 100 cm of the soil surface containing nodules that are strongly cemented with Fe and/or Mn.

Plinthic: a subsurface horizon that consists of Fe-rich, humus-poor mixture of kaolinitic clay with quartz and other constituents, that hardens irreversibly on exposure to repeated wetting and drying.

Protic: showing no soil horizon development.

Rendzic: having a thick, dark surface horizon rich in humus and a neutral soil reaction, that contains or overlies material with a calcium carbonate equivalent of 40% or more.

Rhodic: Having within 150 cm of the soil surface a reddish subsurface layer, 30 cm or more thick, with a Munsell hue that is redder than 5 YR, a value of less than 3.5 when moist and when dry, a value that is no more than one unit higher than when moist.

Salic: having a horizon rich in salt within 100 cm depth.

Sapric: having, after rubbing, less than one-sixth of the organic material consisting of recognisable plant tissue within 100 cm depth.

Silandic: Having one or more layers, cumulatively 30 cm or more thick, with andic properties (Andosols only).

Skeletic: having > 40% (by volume) gravel or other coarse fragments over a depth of 100 cm from the surface.

Sodic: having 15% or more exchangeable sodium plus magnesium within 50 cm depth.

Solodic: having a layer, 15 cm or more thick within 100 cm depth, with a strong columnar or coarse prismatic structure that does not have 15% or more exchangeable sodium plus magnesium.

Stagnic: having stagnation of surface water within 50 cm depth.

Thionic: having a horizon rich in sulphur or a layer with sulphides, 15 cm or more thick within 100 cm depth.

Takyric: having a heavy-textured surface horizon comprising a surface crust and a platy structured lower part.

Tidalic: flooded by tidal water but not covered at average low tide.

Umbric: having a thick, dark surface horizon rich in humus and an acid soil reaction.

Vertic: having a clay-rich subsurface horizon with evidence of movement of soil masses within 100 cm depth.

Vitric: having layer(s), 30 cm or more thick, with a limited to moderate amount of allophane, imogolite or organo-metalic complexes resulting from the weathering of volcanic ash.

Xanthic: having a ferralic horizon that has in a sub-horizon, 30 cm or more thick within 150 cm of the soil surface, a Munsell hue of 7.5 YR or yellower and a value, when moist, of 4 or more and a chroma, when moist, of 5 or more.

Yermic: having a surface horizon of rock fragments embedded in a loamy layer, may be covered by thin wind-blown sand.

Further information on the WRB system can be found in the WRB 2006 Technical Manual [63], which can be downloaded from the WRB page on the FAO website [63a]. (FAO)

Major soil types of Africa

Reader's Tip!

This section presents the major types of soil that can be found in Africa as defined by the Reference Soil Groups of the World Reference Base (WRB) scheme. The following pages aim to help the reader understand the key characteristics of each soil type, their associated landscapes and their broad distribution pattern across Africa.

The soils are presented in two groups: those which have significant areal extent (referred to as the major soil types) and those with a more restricted occurrence across the continent (referred to as the minor soil types). In both cases, the soils are listed alphabetically.

Each block provides a clear definition and simple description of the soil. In addition, the reader is shown a typical profile that illustrates the soil's key characteristics and a typical landscape, land cover or land use that is associated with that soil. For the major soil types, a map indicates the regions where a particular type of soil is dominant. Due to the very small scale of these maps, the less extensive minor soil types cannot be shown.

The colour used in the box surrounding the soil name is the same as the legend of page 64 and for the overview and regional maps shown in pages 68 – 127. In this way, when you see a specific colour on the map (e.g. red), you can locate the same colour in this section to discover the basic characteristics of the soil in question (i.e. red corresponds to Andosols).

It's important to remember that a particular type of soil is not limited to the areas shown on the map and that on a local scale, other soil characteristics may be more significant.

Soil and water conservation structures in Tigray, Ethiopia. Thousands of kilometres of stone bunds were built by hand in a spectacular effort to protect shallow soils (Calcaric Regosols in this example) from further erosion. (KV)

Acrisols

Strongly acid soils with a clay-enriched subsoil and low nutrient-holding capacity (from Latin *acer*, acid)

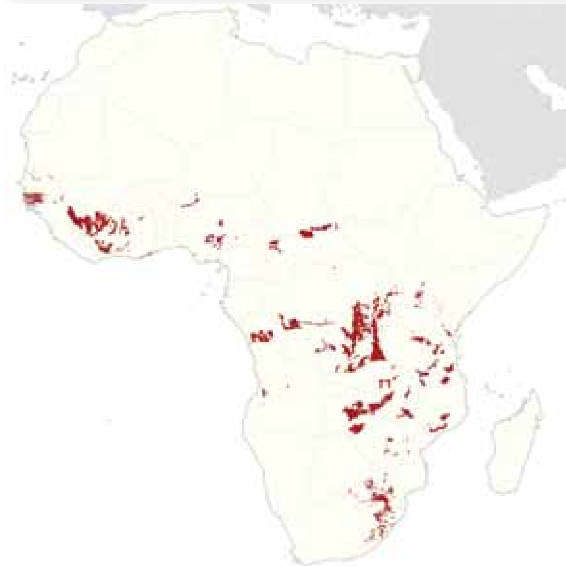
Acrisols are acidic soils dominated by kaolinte and display a clay accumulation horizon in the subsoil. They are quite common in Africa and are mainly found in the wetter parts of the tropics and subtropics. They are normally associated with acidic bedrock and are deficient in nutrients, thus requiring substantial applications of fertiliser to produce satisfactory crop yields.

Left: Manual land preparation on the central plateau of Madagascar at the onset of the rains - note the dark red soil colour. (OS)

Below: Deep red Acrisol in eastern Madagascar with a thin, dark-coloured, surface layer enriched with humus. Clay particles have been lost from the lighter coloured layer by leaching or faunal activity (probably termites). The round, light-coloured areas are old roots and channels of burrowing animals filled with material from above. (OS)

The map shows where Acrisols are dominant. They cover around 3% of Africa.

Soil Taxonomy classifies most of these soils as Ultisols.



Alisols

Very acid soils with a clay-enriched subsoil and high nutrient-holding capacity (from Latin *alumen*, alum)

Alisols have a higher clay content in the subsoil than in the topsoil as a result of clay migration. Alisols have a low base saturation at certain depths and high-activity clays (e.g. vermiculite, illite and montmorillonite) are present in the clay-rich horizon. The acidity is caused by the weathering of minerals which release a large amount of aluminium - often at levels that are toxic to most crops. They occur predominantly in humid tropical, humid subtropical and warm temperate regions.

Left: Undulating landscape over sandstone in Natal, South Africa. The vegetation is semi-natural grassland grazed by goats and sheep. (ISRIC);

Below: Deep, red Alisol from Natal, South Africa. The soil has a dark, humus-enriched surface layer. The acid nature of the soil inhibits deep rooting. The bright red and yellow spots at about 1 m depth indicate a layer of iron accumulation which must remain moist to prevent hardening. (ISRIC); The map shows where Alisols are dominant. They cover around 1% of Africa.

Soil Taxonomy classifies most of these soils as Ultisols.

Andosols

Young soil developed in volcanic deposits (from Japanese *an*, black and *do*, soil)

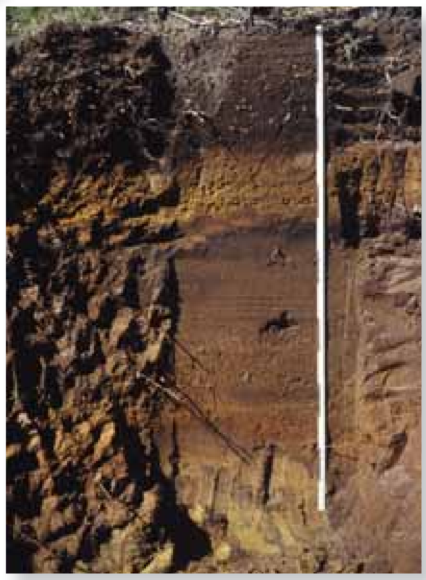
Andosols develop from materials ejected from volcanoes (e.g. ash, pumice, cinder) which weather to produce specific clay minerals. In more humid climates, many Andosols develop a thick, dark topsoil as a result of the fixing of organic substances by aluminium that is released from the weathering of the clay minerals. Andosols are found along the Rift Valley in Eastern Africa, around Mount Cameroon,and in Madagascar. They have a high potential for agricultural production, but many suffer from strong phosphorus fixation due to high levels of active iron and aluminium.

Left: Andosols are found on the slopes of volcanoes or in areas that have received ash, pumice or cinders from an eruption. The picture shows volcanic cones of the Virunga Mountains on the border between Rwanda, the DR Congo and Uganda. There are many active and extinct volcanoes along the African Rift Valley. (SDD)

Below: This profile shows clear layering as a result of intermittent eruptions of Mount Kenya. The upper 50 cm represent the youngest soil. An older soil occurs below in which the original, dark-coloured surface layer is still visible. (ISRIC)

The map shows where Andosols are dominant. They cover less than 1% of Africa.

Soil Taxonomy classifies most of these soils as Andisols.



Arenosols

Easily erodable sandy soil with low water- and nutrient-holding capacity (from Latin, *arena*, meaning sand).

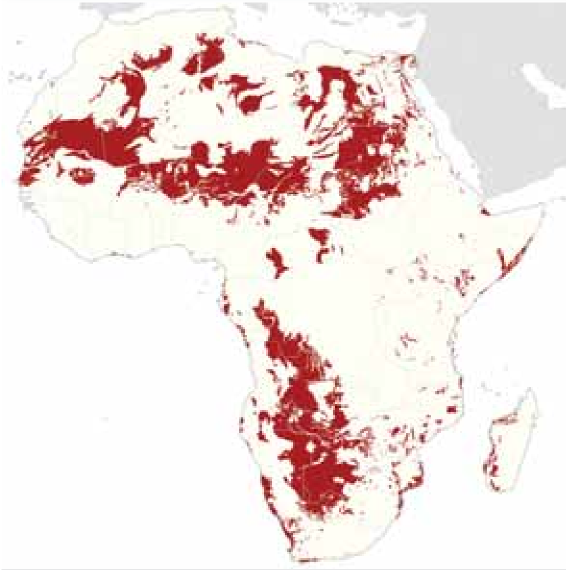
Arensols develop as a result of the in situ weathering of quartz-rich parent material or in recently deposited sands (e.g. dunes in deserts and beaches). They are among the most extensive soil types in the world and are the dominant soil in Africa. The Kalahari Sands is the largest body of sand on Earth. Soil formation is often limited by a low weathering rate. If vegetation has not developed, they can be prone to wind erosion. Once vegetated, the accumulation of organic matter, clay bands or the formation of humus-aluminium complexes can occur.

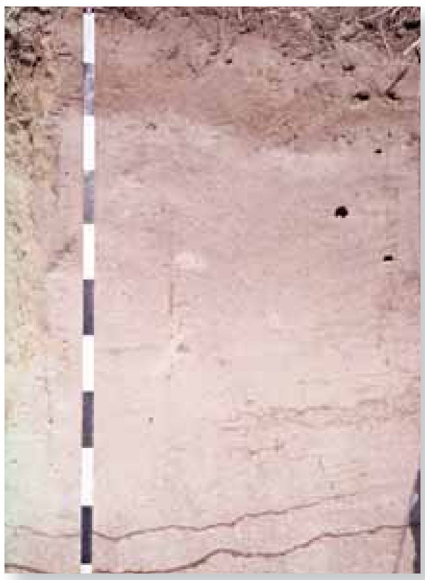
Left: Attempts to stablise migrating sand dunes in southern Tunisia using date-frond fences. Left unchecked, dune systems can engulf villages and fields. (TG)

Below: Deep, sandy soil with thin, clay-rich bands in South Africa. Clay migrates through the soil with percolating water and is deposited in bands where the wetting front stops. The presence of these bands enhances the water-holding capacity just enough for crops to survive short dry spells. The holes are burrows. (ISRIC)

The map shows where Arenosols are dominant. They cover around 22% of Africa.

Soil Taxonomy classifies most of these soils as Psamments.





Calcisols

Soil with significant accumulation of calcium carbonates, generally found in dry areas (from Latin *calcarius*, lime-rich)

Calcisols occur in many parts of Africa, especially where the climate is dry enough to allow the accumulation of calcium carbonate in the soil. They form through the leaching of carbonates from the upper part of the soil which precipitate when the subsoil becomes oversaturated, from carbonate-rich water moving through the soil or by the evaporation of water which leaves behind dissolved carbonates. Precipitated calcium carbonate can fill the pores in the soil, thereby acting as a cementing agent, and can form a solid hard pan (calcrete) that is impenetrable to plant roots.

Left: Extensive grazing is one of the few options on dry Calcisols. (EM)

Below: a typical Calcisol landscape in Namibia. The carbonate enrichment is such that a hard calcrete layer has developed 20 cm below the surface. (EM)

The map shows where Calcisols are dominant. They cover around 6% of Africa.

Soil Taxonomy classifies most of these soils as Calcids.

Cambisols

Soil that is only moderately developed on account of limited age (from Latin *cambiare*, to change)

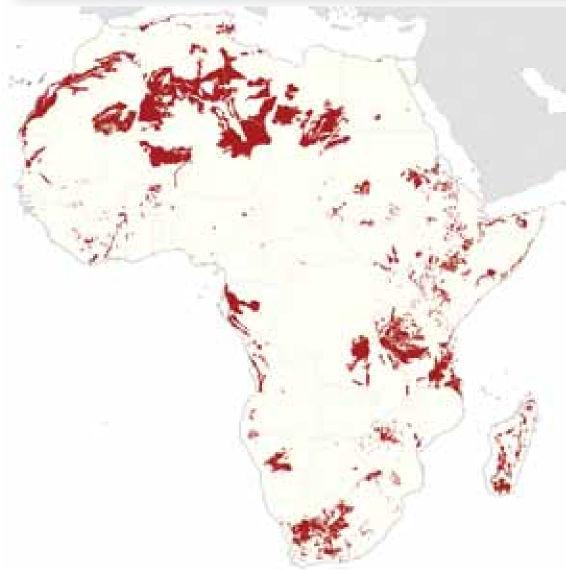
These are young soils. Generally lacking distinct horizons, Cambisols exhibit only slight evidence of soil-forming processes usually through variations in colour, the formation of structure or presence of clay minerals. They are extensive throughout Africa and can have varied characteristics depending on the nature of the parent material, climate and terrain.

Left: Chromic Cambisol at Tsetsera Sussundenga district in Mozambique. Incipient soil formation has resulted in a distinctive red colour due to high levels of iron oxide. (SDD)

Below: A profile of a deep Cambisol in Rwanda. Roots of plants extend deep into the subsoil to obtain nutrients from freshly weathering minerals. (ISRIC)

The map shows where Cambisols are dominant. They cover around 11% of Africa.

Soil Taxonomy classifies most of these soils as Inceptisols.



Ferralsols

Strongly weathered soils with low nutrient-holding capacity (from Latin *ferrum*, iron and *alumen*, alum)

Ferralsols are widespread in Central, Eastern and Southern Africa. Mostly associated with high rainfall areas and very old (Tertiary) land surfaces, they are strongly leached soils that have lost nearly all of their weatherable minerals over time. As a result, they are dominated by stable products such as aluminium oxides, iron oxides and kaolinite which give Ferralsols their strong red and yellow colours. Levels of calcium and magnesium are very low. The binding of particles by iron oxides gives an apparent sandy or silty feeling (pseudosand).

Left: In very acid soils, such as on this Arenic Ferralsol on the Makonde Plateau, Tanzania, plants such as pineapple (*Ananas comosus*) are a good choice as an intercrop with cashew (*Anacardium occidentale*). (JD)

Below: An Acric Ferralsol from the Mtwara District of Tanzania (the centre of the disastrous Tanganyika groundnut scheme – see page 45). Noticeable is the characteristic lack of layering in the profile as a result of biological mixing and the low organic matter content of the topsoil. (SDD)

The map shows where Ferralsols are dominant. They cover around 10% of Africa.

Soil Taxonomy classifies most of these soils as Oxisols.

Fluvisols

Young soil in floodplains, lakes, deltas or marine deposits (from Latin *fluvius*, river)

Fluvisols occur in all periodically flooded areas such as flood plains, river fans, valleys, tidal marshes and mangroves throughout Africa. Fluvisols show a layering of sediments with pedogenic horizons as a result of deposition by water. Their characteristics and fertility depend on the nature and sequence of the sediments and length of periods of soil formation after or between flood events. High water velocities or turbulent action gives rise to gravelly or sandy soils. Low velocities or standing water give rise to fine-textured soils, often mixed with significant amounts of organic debris.

Left: Fluvisol along the bank of the Zambezi River in Zimbabwe. The layered structure of the soil, caused by the deposition of new material during floods, is evident. (OS)

Below: Distinctive horizontal strata of a Fluvisol in the bank of the Manafwa River, Uganda. Banana plants thrive in the fertile, loamy soils which receive biannually fresh sediment originating from landslides on Mount Elgon (see page 158). (JD)

The map shows where Fluvisols are dominant and clearly denotes the major river network. They cover around 3% of Africa.

Soil Taxonomy classifies most of these soils as Fluvents.

Gleysols

Soils saturated by groundwater for long periods (from Russian *gley*, 'mucky mass')

Gleysols occur in low-lying areas or depressions where the groundwater comes close to the surface and the soil is saturated with water for long periods of time. Gleysols display characteristic reddish, brownish or yellowish colours in the upper part of the soil where oxygen is present, in combination with greyish/bluish colours deeper in the soil where oxygen is absent (reduced). Often Gleysols are found with wetland vegetation (e.g. grass, reeds, sedges). Because of their wetness, Gleysols show little soil development apart from accumulation of organic matter in the surface layer and rust mottling.

Left: Typical Gleysol landscape with standing water between the Kafue and Zambezi Rivers in central Zambia. (OS)

Below: Completely reduced Gleysol from the Niger River delta, Nigeria. (OS)

The map shows where Gleysols are dominant. They cover around 2% of Africa.

Soil Taxonomy classifies most of these soils as aquic suborders.

Gypsisols

Soil with significant accumulation of gypsum, generally found in dry areas (from Greek *gypsos*, gypsum)

Gypsisols are soils with substantial (secondary) accumulation of gypsum ($CaSO_4.2H_2O$). They are found in the driest parts of the arid climate zone, and in Africa the are predominantly found in the northern Sahara. Many Gypsisols occur in depressions and reflect former lake beds that have dried up through evaporation. The processes for gypsum precipitation are similar to Calcisols (see previous page). Gypsum that forms a solid hard pan is referred to as gypcrete. Natural vegetation is sparse and dominated by xerophytic shrubs or ephemeral grasses.

Left: Gypsisols under a semi-arid climate around the Chott Djerid in Tunisia. Hardened gypcrete is common in this region. (AJ)

Below: A Gypsisol profile from Makanya in Tanzania (southwest of Mt. Kilimanjaro). Above the knife, the soil has a non-cemented horizon containing significant amounts of secondary accumulation of gypsum. Below the knife, a harder (more indurated), petrogypsic horizon is evident. (JD)

The map shows where Gypsisols are dominant. They cover nearly 2% of Africa.

Soil Taxonomy classifies most of these soils as Gypsids.

Histosols

Soils with a large amount of organic material generally developed under excess water or cold conditions (from Greek *histos*, tissue)

Histosols, also known as peat, contain a high amount of organic matter, usually more than 20%, and have a high water content. Their bulk density is very low and when drained, they suffer from irreversible shrinkage and surface subsidence. Histosols are rather rare in Africa, occurring mostly in wetlands, isolated pockets in low-lying areas or depressions and in coastal regions where organic debris accumulates. Their distribution is limited by the rapid decomposition of organic material in tropical regions due to the permanently high temperatures.

Left: Histosols are typical of wetlands. This small depression is in the vast rainforest of the Ivindo National Park in Gabon. (BM)

Below: A Histosol on the slopes of Mount Bisoke – extinct volcano in the Virunga Mountains of Rwanda. In the Virungas, peat is found in swampy conditions at high altitudes. (SDD)

While Histosols may be significant locally, their distribution accounts for less than 1% of Africa.

Soil Taxonomy classifies these soils as Histosols.

Leptosols

Shallow soil over hard rock or gravelly material (from Greek *leptos*, thin).

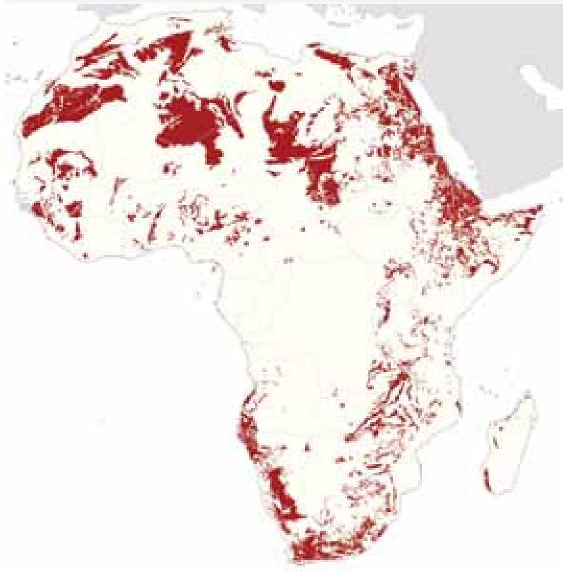
Leptosols are shallow soils over hard rock, very gravelly material or highly calcareous deposits. Because of limited pedogenic development, Leptosols have a weak soil structure. Leptosols occur all over Africa, especially in mountainous and desert regions where hard rock is exposed or comes close to the surface and the physical disintegration of rocks due to freeze/thaw or heating/cooling cycles are the main soil-forming processes. In WRB, bare rocks exposes at the surface (possibly displaying only microscopic soil formation) are referred to as Nudilithic Leptosols.

Left: Rock outcrops are typical of Leptosol landscapes. Trees must be shallow rooting or develop where the soil is a little deeper and where impeded drainage can lead to higher water retention. (EM)

Below: Leptosol from Ethiopia – a cover of debris some 20 cm thick overlies a dolerite. Soil development is slow. Only limited extensive grazing is possible. (JD)

The map shows where Leptosols are dominant. They cover around 17% of Africa.

Soil Taxonomy classifies most of these soils as Entisols.



Lixisols

Slightly acid soils with a clay-enriched subsoil and low nutrient-holding capacity (from Latin *lixivia*, washed-out substances)

Lixisols are slightly acid soils that show a distinct increase in clay content with depth. The clay is predominantly kaolinite with limited capacity to hold nutrients. Occurring mainly in the dry savannah region with low biomass production, Lixisols do not hold much organic matter and lack a well developed soil structure. High-intensity rainfall will destroy any soil structure present making Lixisols prone to erosion. If the soil is not protected, a crust may develop which prevents rain entering the soil. Overland flow will then erode the topsoil which is the most fertile part. Wind erosion may be an issue as loose soil particles at the surface can easily be blown away.

Left: A cultivated Lixisol from Tanzania. Note the use of sorghum stalks as a mulch to protect the soil from erosion. (OS)

Below: A characteristically red Lixisol from Tanzania. (EM)

The map shows where Lixisols are dominant. They cover around 4% of Africa.

Soil Taxonomy classifies most of these soils as Alfisols.

Luvisols

Slightly acid soils with a clay-enriched subsoil and high nutrient-holding capacity (from Latin *luere*, to wash).

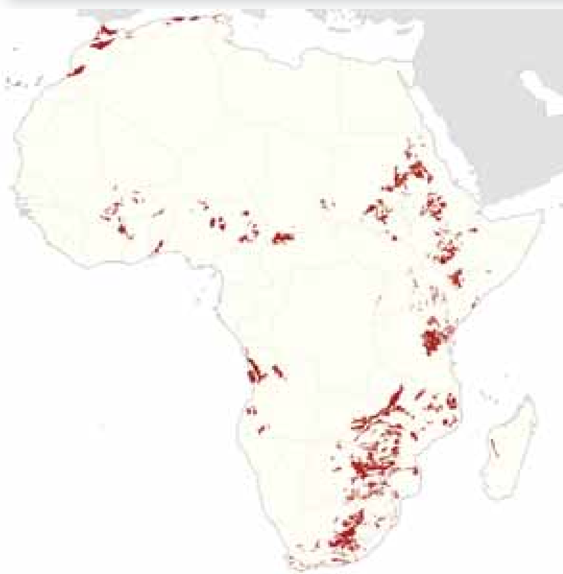
Luvisols have a distinct increase in clay content with depth as a result of clay movement from the upper part of the soil to the lower part. The clay is usually a mixture of kaolinite, illite and montmorillonite, giving the soil a high nutrient-holding capacity. In general, Luvisols have a well-developed soil structure, which contributes to a good water-holding capacity. Luvisols in Africa are mainly found in the Mediterranean region and in the southern and eastern parts of Africa on relatively young surfaces.

Left: Drip-irrigated cultivation on Luvisols in Morocco. Note the virtual absence of a darker coloured surface layer, indicating that this soil is poor in organic matter. (OS)

Below: Red Luvisol from Botswana – note the deep rooting and the much better developed soil structure compared to the Lixisosl. (ISRIC)

The map shows where Luvisols are dominant. They cover around 4% of Africa.

Soil Taxonomy classifies most of these soils as Alfisols.



Nitisols

Deep red soils with a well developed, nut-shaped structure (from Latin *nitidus*, shiny)

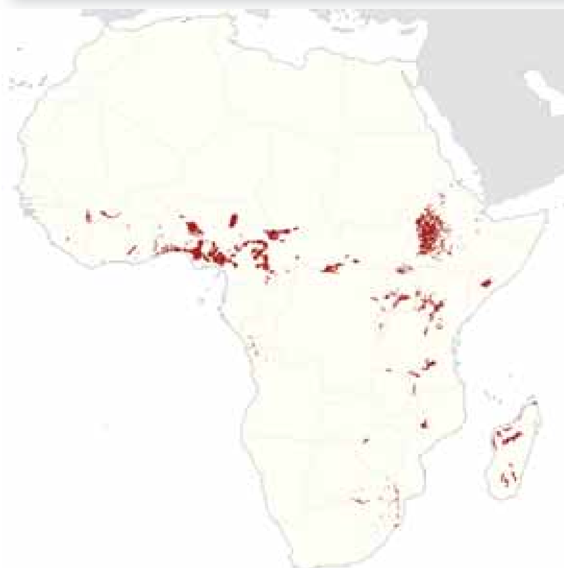
Nitisols develop mainly from basic iron-rich rocks such as basalt. Their main characteristics are a dark red colour and a well-developed structure that is nutty in appearance with shiny surfaces. The active iron content (i.e. amorphous iron oxides and hydroxides) is high, which enforces strong bonding of soil particles and the formation of the nut-shaped aggregates. The shiny surfaces are a mixture of clay and iron coatings. Most Nitisols are dominated by kaolinite clay. While common in eastern Africa, they also occur in many other parts of Africa.

Left: Nitisols are much sought after because of their high productivity despite a high phosphate-fixing capacity. Coffee crop on Nitisols in the highlands of Kenya. (ISRIC)

Below: Nitisols are mainly developed in highly weathered products of basic igneous parent rock. This Nitisol from Benin shows a well-developed structure. Rooting is limited to the upper part of the soil due to strong acidity and high aluminium toxicity in the subsoil. (OS)

The map shows where Nitisols are dominant. They cover around 2% of Africa.

Soil Taxonomy classifies most of these soils as Oxisols.



Phaeozems

Slightly acid soils with a thick, dark-coloured surface layer (from the Greek *phaios*, dusk and Russian, *zemlja*, earth or land)

Phaeozems are characterised by their, thick, dark-coloured, surface layer which is rich in organic matter and well-supplied with nutrients. Their development requires a reasonable amount of precipitation and a lush vegetation, preferably grasses. This characteristic distinguishes them from Chernozems, which they border where conditions are wetter, and Kastanozems where conditions are drier. Outside Africa, they are typical prairie soils. Most Phaeozems in Africa occur in the highlands, but their distribution is quite limited.

Left: Strip cultivation along contours on Phaeozems in South Africa to prevent erosion. (ISRIC)

Below: Phaeozem on exfoliating dolerite in Natal, South Africa. (ISRIC)

The map shows where Phaeozems are dominant. They cover less than 1% of Africa.

Soil Taxonomy classifies most of these soils as Mollisols.

Planosols

Poorly structured surface layer abruptly overlying a slowly permeable layer (from Latin *planus*, flat)

The most important characteristic of Planosols is the very slow permeability of the subsoil which causes water entering the soil to stagnate above this layer. The transition to the slowly permeable layer is very sharp - clay content at least doubles or significantly increases. As a result of the frequent waterlogging in the topsoil, iron and manganese are dissolved and precipitated as reddish-brown or black concretions on both sides of the abrupt boundary. The removal of iron in the topsoil causes the structure to collapse. Therefore, most Planosols have a structureless topsoil.

Left: Bricks made from material from the bleached horizon of Planosols in southwestern Ethiopia. (EVR)

Below: Planosol from Ethiopia. The abrupt textural change at 40 cm depth is clearly visible. The surface layer is almost structureless and has a thin (5 cm) organic layer. (EVR)

The map shows where Planosols are dominant. They cover just over 1% of Africa.

Soil Taxonomy classifies most of these soils as Albaqualfs and Albaquults.

Plinthosols

Soils with accumulation of iron that hardens irreversibly when exposed to air and sunlight (from Greek *plinthos*, brick)

Plinthosols display an accumulation of iron (and manganese) in the subsoil as large mottles or concretions. This iron-rich layer develops mostly under the influence of fluctuating groundwater. While buried, the layer (called plinthite) is soft and can be cut by a knife. However, once exposed to air and sunlight, it hardens irreversibly and is often known as ironstone). When brought to the surface by erosion, the hard ironstone layer forms a cap that protects the area from further erosion. Non-protected areas continue to erode and what originally were the lower parts became the highest parts in the landscape. This phenomenon is known as landscape inversion.

Left: Tableland landscape in northern Burkina Faso defined by an old ironstone cap. Over time the ironstone cap and protected slopes are degraded to give a catena of Petric Plinthosols, Pisoplinthic Plinthosols and Eutric Plinthosols, with Regosols in the upper part of the slope. (MB/IRD)

Below: Plinthosol in Ghana. The iron-rich layer starts at 70 cm depth and occurs here as interconnected mottles. (ISRIC)

The map shows where Plinthosols are dominant. They cover around 5% of Africa.

Soil Taxonomy classifies most of these soils with the Plinth- prefix of Ultisols and Oxysols.

Regosols

Weakly developed soils in unconsolidated material (from Greek *rhegos*, blanket)

Regosols are weakly developed mineral soils in unconsolidated medium and fine-textured material - more coarse-textured soils are Arenosols (in the case of sand) or Leptosols (in the case of gravel). Regosols show only slight signs of soil development - some accumulation of organic matter producing a somewhat darker topsoil is often the only evidence of soil formation. Limiting factors for soil development range from low temperatures, prolonged dryness, characteristics of the parent material or erosion. Regosols are extensive in eroding lands such as mountains or deserts where soil formation is generally absent.

Left: Landscape with Regosols in the Middle Atlas of Morocco - gullies that have developed by the overland flow of rainwater and bare areas due to sheet erosion are clearly visible - rock outcrops are often common. (AR)

Below: Regosol on weathering tilted schist in the Anti Atlas mountains of Central Morocco. The loosened mixture of gravels and fine earth is heavily affected by slope processes, giving little chance for soil formation. (OS)

The map shows where Regosols are dominant. They cover around 3% of Africa.

Soil Taxonomy classifies most of these soils as Entisols.

Solonchaks

Soils with accumulation of salt (from Russian *sol*, salt)

Solonchaks are strongly saline with high concentrations of soluble salts. They are mostly associated with arid regions and with areas where saline groundwater comes close to the surface or where evapo-transpiration rates are considerably higher than precipitation, at least during a large part of the year. Salts dissolved in soil moisture remain behind after the evaporation of the water and accumulate on or just below the surface. Their characteristics and limitations to plant growth depend on the amount, depth and composition of the salts.

Left: A salt flat with Halophyte vegetation in Namibia. Recent water has evaporated leaving a distinctive 'puffed' up surface that collapses if walked upon. (EM)

Below: A Solonchak from southern Morocco. The white surface layer with a thickness of about 50 cm is very rich in soluble salt derived from slightly saline groundwater at a depth of 5 m which comes to the surface by capillary rise. (AR)

The map shows where Solonchaks are dominant. They cover around 1% of Africa.

Soil Taxonomy classifies most of these soils as Salids.

Solonetz

Soil with a clay accumulation horizon, rich in sodium (from the Russian, *sol*, meaning salt and *etz*, meaning strongly expressed).

Solonetz are strongly alkaline soils. They display with a dense, clay-rich subsoil containing a high amount of exchangeable sodium and a distinctive columnar structure. Sodium has the ability to disperse clay particles and organic matter in the topsoil, which are subsequently washed deeper into the soil. Large pores are filled with clay and structural elements capped with organic coatings. Solonetz are normally associated with flat lands in climates with hot, dry summers or with former coastal deposits that contain a high proportion of salt.

Left: An eroding Solonetz landscape from South Africa with salt tolerant vegetation. (EM)

Below: Solonetz from Namibia. The profile shows light coloured surface horizon (0-20 cm) overlaying a dense, strongly structured, sodium-rich subsoil horizon (20-80 cm) that exhibits a blocky or columnar top. Note the abrupt transition to the sodium-rich subsoil. (EM)

The map shows where Solonnetz are dominant. They cover around 1% of Africa.

Soil Taxonomy classifies most of these soils as Aridisols.

Umbrisols

Acidic soil with a dark surface horizon rich in organic matter (from Latin *umbra*, shade)

Umbrisols have a deep, dark-coloured surface layer that is rich in organic matter but has a low nutrient content. They are mainly associated with acid parent materials and areas with high rainfall. In Africa they mainly occur in mountains and highland regions and on sandy soils in the tropics in areas with high rainfall. Umbrisols are the counterpart of nutrient-rich soils with a dark surface horizon (i.e. Chernozems, Kastanozems and Phaeozems).

Left: Permanent grasslands in Natal, South Africa, give rise to significant organic matter levels in the topsoils of shallow Umbrisols that have developed on the weathering products of shale and siltstone. (EM)

Below: Umbrisol from central Angola in Kalahari sand; although the soil has a Podzol morphology (dark topsoil over an ash-white layer on top of a brownish subsoil), the content in organic carbon of the subsoil is far below the required amount. (JAR)

The map shows where Umbrisols are dominant. They cover less than 1% of Africa.

Soil Taxonomy classifies most of these soils as Entisols and Inceptisols.

Vertisols

Clay-rich soils that develop deep, wide cracks upon drying (from Latin *vertere*, to turn)

Vertisols are clayey soils that exhibit wide cracks which open and close periodically upon drying and wetting. This is caused by the presence of the clay mineral, montmorillonite, which takes up water when it becomes wet (and expands) and releases the water again upon drying out (shrinks). This process brings material from the surface into the subsoil giving rise to a 'mixed or churned' soil (see page 27). Vertisols are widespread in Africa; especially in the Maghreb, Sudan and Ethiopia.

Left: Ethiopian farmer on the way to plough his Vertisol land with the traditional Maresha plough. (JD)

Below: Black Vertisol from near Jimma in Ethiopia. The photo shows wedge-shaped structural elements (sphenoids) with smoothened surfaces formed by shear stresses on moistening (typical for Vertisols). (EVR)

The map shows where Vertisols are dominant. They cover around 3% of Africa.

Soil Taxonomy classifies most of these soils as Vertisols.

While all the soil types on this spread may be important locally, their overall extents are generally limited (<0.5% of the land surface of Africa) and their distribution is too sparse to display on very small-scale maps.

Anthrosols

Soil formed or modified by agricultural activity over a long period of time (from Greek *anthropos*, man)

Anthrosols are formed through human activities such as the addition of organic material, household wastes, lime, charcoal, earth-sods or mineral matter. The added material is usually deeply tilled into the original soil. In most cases, a buried soil can still be found at some depth from the surface. Anthrosols include 'Paddy Soil' where the long-term cultivation of rice causes unique soil characteristics as a result of the repeated lack of oxygen. The morphological and chemical characteristics of these soils vary and depend on the specific human activity.

Left: Profile of an Anthrosol that has developed in a valley bottom vegetable garden in the Usambara Mountains in Tanzania through the addition of earthy manures, compost or muds over a long period of time. (JD)

Below: Due to their high organic matter content and good soil structure, Anthrosols are intensively cultivated. (SG)

On a continental scale, Anthrosols are rarely dominant but locally can be very important.

Soil Taxonomy classifies then as Anthreps.

Chernozems

Soil with a deep, dark topsoil that is rich in organic matter (from Russian *chern* black, and *zemlja*, earth).

Chernozems have a very dark-brown or blackish surface horizon with a significant accumulation of organic matter and a neutral pH. Secondary calcium carbonate deposits occur within 50 cm of the lower limit of the humus-rich horizon. They show high biological activity and are typically found in the long-grassland areas in humid-temperate climates (e.g. prairies). Chernozems are among the most productive soil types in the world.

Left: A Chernozem from the coastal plain south of Rabat, Morocco. The darker topsoil (0 – 45 cm) contains significant amounts of organic matter. The lighter material in the subsoil is calcium carbonate. Chernozems are very rare in Africa. (OS)

Below: Considered as one of the world's best soils, this Chernozem in Morocco supports the cultivation of cereal crops. Irrigation may be required in dry conditions. (EM)

Soil Taxonomy classifies these soils as Mollisols.

Cryosols

Soil of cold regions with permafrost and/or cryoturbation (from Greek *kraios*, cold or ice)

Cryosols develop in cold regions where permanently frozen subsoil (permafrost) is found. In this type of soil, water occurs primarily in the form of ice and cryogenic processes such as freeze-thawing cycles, cryoturbation (warping), frost heave, cryogenic sorting, cracking and ice segregation are the dominant soil-forming processes. Cryosols often exhibit distorted horizons and/or patterned ground.

Left: A 10 cm organic layer on the top of a highly cryoturbated (mixed) horizon (10–70 cm) with permafrost at 70 cm. The cavity at the base of the profile is caused by melting of the ice due to the excavation of the soil pit. The grey colours indicate waterlogging. Photographs from Africa are very difficult to find – this example is from Siberia! (SB)

Below: The snow-covered summit of Kilimanjaro. While their distribution is very small on a continental basis, this arctic environment also occurs on Mount Kenya and on the Ruwenzori. (PDI)

Soil Taxonomy classifies most of these soils as Gelisols.

Durisols

Soils with accumulation of silica (from Latin *durus*, meaning hard)

Durisols are associated with old surfaces in arid and semi-arid environments in western South Africa, southern Namibia and along the coast of Morocco. They display hardened (secondary) accumulations of silica (SiO_2) in the soil. Durisols develop over long periods during which the soil reaction is so alkaline ($pH > 8$) that silicon becomes mobile. The dissolved silicon precipitates as an amorphous opal, nodules (durinodes) and eventually, hard layers known as duripans develop (in South Africa these are known as dorbanks). Eventually, such hard pans may turn into silcrete.

Left: Durisol with hard pan and a shallow, loose topsoil in South Africa. (FE)

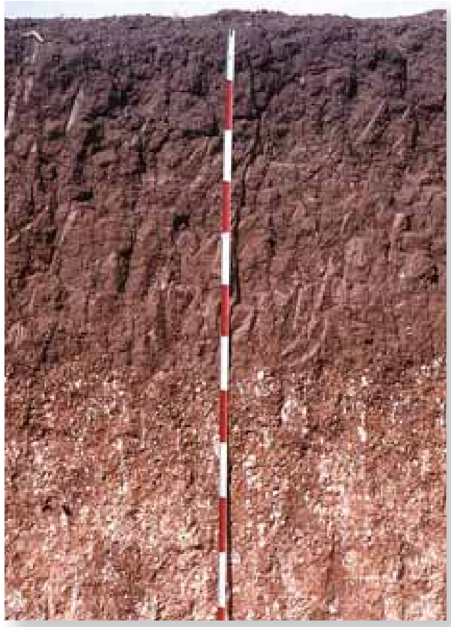
Below: Duripan capping an old land surface in South Africa. Below the soil, a deeply weathered white rock is visible. (FE)

While locally significant, on a continental scale, Durisols occupy less than 0.5% of Africa.

Soil Taxonomy classifies most of these soils as Durids.

Kastanozems

Soil with an organic-rich surface horizon and calcium carbonate or gypsum accumulation in the subsoil (from Latin *castanea*, chestnut, and Russian *zemlja*, earth)



Kastanozems have a deep, dark coloured surface layer with a significant accumulation of organic matter and high base saturation and an accumulation of (secondary) calcium carbonate in the subsoil. Kastanozems are mostly found in the Mediterranean part of Africa and as localised occurrences in southern Africa. They develop in the drier parts of the savannah regions where there is still sufficient biomass production to form the organic-rich surface layer and dry enough to facilitate the precipitation of carbonates or gypsum.

Left: Kastanozem from the Triffa Plain, Morocco, showing a dark coloured, humus-rich surface layer. Secondary calcium carbonate is visible below 70 cm. (AR)

Below: Hill slopes in the Rif Mountains, Morocco. The dark areas correspond to Kastanozems, lighter patches are Calcisols - a result of topsoil erosion. (SH)

While locally they may be significant, on a continental scale, Kastanozems occupy less than 0.5% of Africa.

Soil Taxonomy classifies most of these soils as Mollisols.

Podzols

Acid soil with a bleached horizon underlain by an accumulation of organic matter, aluminium and iron (from Russian *pod*, under, and *zola*, ash)

Podzols have a distinctive ash-grey horizon which has been bleached by the loss of organic matter and iron oxides. This sits on top of a dark accumulation horizon of redeposited humus and/or reddish iron compounds. Typically occurring in temperate zones, Podzols are not well developed in Africa; most of them barely exhibit the ash-grey layer and the amount of accumulated organic matter in the subsoil is not very high. Podzols have been recorded in the Kalahari Sands (Angola), Congo, Zambia, South Africa and Zimbabwe and some coastal sand deposits in western Africa.

Left: A classic Podzol in saprolite from southern South Africa showing a contrasting grey leached horizon overlaying a dark reddish-brown iron and humus accumulation horizon. (MP)

Below: Road construction in Côte d'Ivoire. The white sand is the bleached layer of the Podzol. Once left bare, vegetation will have great difficulties to re-establish itself. (AR)

Podzols are not widespread on a continental scale and occupy less than 0.5% of Africa.

Soil Taxonomy classifies most of these soils as Spodosols.

Stagnosols

Soils with periodic water stagnation (from Latin *stagnare*, to flood)

Stagnosols are soils with a perched water table, often caused by the presence of an impermeable barrier deep in the soil. Perched water tables lead to temporary water logging and the mobilisation of iron and/or manganese. This process gives rise to a characteristic colour pattern; aggregate surfaces are bleached and depleted of iron whereas the centres are enriched showing brown to orange colours. A common name in many national classification systems is pseudogley. They have been recorded in Côte d'Ivoire, Central African Republic and Chad.

Left: A vertical section in a Stagnosol shows the intricate colour patterns that exist in such soil. (RS)

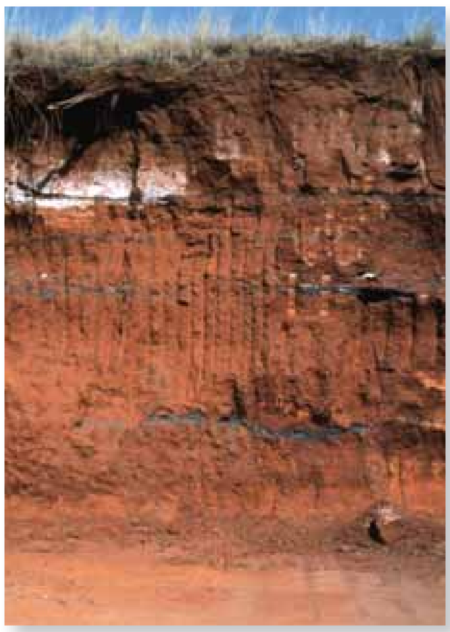
Below: Surface ponding of water and stagnant conditions after rainfall is characteristic of Stagnosols. (EM)

While locally they may be significant, on a continental scale, Chernozems occupy less than 0.5% of Africa.

Soil Taxonomy classifies most of these soils as the epiaquic members of Inceptisols.

Technosols

Soils that are sealed or contain a significant amount of artefacts (from Greek technikos, skilfully made)



Technosols contain large quantities of man-made artefacts (e.g. household garbage or industrial waste), or contain material that has been brought to the surface (e.g. mine dumps or oil spills) or are soils that have been sealed by an artificial surface (e.g. roads, hard standing areas). They often contain toxic material. Most Technosols occur in and around urban areas and mining areas.

Left: Technosol from South Africa containing layers of coal. (OS)

Below: Mine dumps and wastes are considered Technosols. The grey and white heaps in the background (left-side) of the image shows spoil and waste ground associated with an opencast copper mine north of Lubumbashi in Katanga, DR Congo. (EVR)

While locally they may be very significant, on a continental scale, Technosols occupy less than 0.5% of Africa.

While Technosols are referred to as urban or mine soil, there are no equivalents in Soil Taxonomy.

African Soils: Strengths, Weaknesses, Opportunities and Threats

This section highlights the strengths, weaknesses, opportunities and threats for each of the main soil types found in Africa.

Acrisols

Strengths: Usually under natural vegetation but can support some agriculture if managed appropriately.

Weaknesses: In climates with a pronounced dry season Acrisols may become very hard; land preparation for the next rainy season is tough, especially by hand.

Opportunities: Can be productive if fertiliser is applied. However, doses must be in small, regular quantities that are applied close to the plants as Acrisols do not have the capacity to hold large amounts of nutrients. Acid-tolerant crops such as pineapple or tea and low-demanding crops such as cassava can do well, but care is needed to protect the soil when the surface is left bare for significant periods. Frequent loosening of the topsoil, together with removal of weeds, will permit rain to infiltrate thus preventing erosion by sheetwash.

Threats: Acrisols are notorious for their susceptibility to erosion and capping once left bare. As their productivity is low, they are best left under natural vegetation.

Alisols

Strengths: Alisols are potentially fertile soils once soil acidity is reduced by liming and the soil is replenished with nutrients. After restoration of the soil's fertility, Alisols may have been transformed into Luvisols and a wide range of crops can be successfully grown. Increasingly, Alisols are planted with acid-tolerant estate crops such as tea, rubber or oil-palm.

Weaknesses: Very acid - caused by rapid weathering of minerals which release a large amount of aluminium into the soil. Often levels of aluminium are so high that they are toxic to most crops. In subsistence agriculture their productivity is low as regeneration from chemical exhaustion is slow.

Opportunities: Shallow-rooting crops can be cultivated thus avoiding the acidic subsoil.

Threats: Once left fallow, Alisols are very prone to erosion.

Andosols

Strengths: Andosols are high in nutrients and easy to cultivate.

Weaknesses: High levels of phosphate fertiliser are needed to affect yields due to fixation by iron compounds in soil. The use of heavy machinery may pose problems because of their low bearing capacity, prone to smearing and stickiness.

Opportunities: They can be planted with a wide variety of crops such as sugar cane, tobacco, sweet potato (tolerant to low phosphate levels), tea, vegetables wheat and orchard crops.

Threats: Andosols on steep slopes are best kept under forest to prevent erosion.

Anthrosols

Strengths: Favourable physical properties for cultivation (porosity, rootability and moisture availability).

Weaknesses: If not maintained, may have less satisfactory chemical characteristics (acidity, nutrient deficiencies). Sufficient manpower and supply of soil improvement media must be readily available.

Opportunities: Provide cultivation opportunities in unfavourable natural conditions – support local produce.

Threats: Land abandonment, climate change.

Arenosols

Strengths: Sandy soils are easy to work and therefore much sought after by farmers.

Weaknesses: They only hold a small amount of organic matter, nutrients and water. Crops have to be irrigated frequently to provide the necessary moisture.

Opportunities: As Arenosols occur mainly in the drier parts of the continent, land use is normally limited to extensive (nomadic) grazing.

Threats: Without good soil conservation measures, Arenosols are prone to wind erosion. Wind breaks are essential in conserving the soil, which is easily turned into shifting sands and dunes.

Calcisols

Strengths: Cultivation can often be successful with irrigation.

Weaknesses: High pH unsuitable for many crops. Fertilisation with nitrogen, phosphorus and trace elements like iron and zinc may be necessary as these are only available naturally in small amounts.

Opportunities: In the Mediterranean region, extensive areas are used for the production of irrigated winter wheat, melons and cotton.

Threats: Lack of vegetation makes them prone to wind and water erosion. Crusts can develop easily.

Cambisols

Strengths: Cambisols are among the better agricultural soils in Africa as they are less depleted of nutrients than other tropical soils and have a sufficiently high nutrient-holding capacity to retain fertilisers.

Weaknesses: Strongly weathered Cambisols contain limited amounts of nutrients.

Opportunities: Depending on their depth, their water-holding capacity can be high.

Threats: In hilly or mountainous areas, where Cambisols are most frequent, care should be taken to prevent erosion when the surface is bare. In such conditions, these soils are best be kept under forest or perennial crops such as tea.

Chernozems

Strengths: Very fertile soils.

Weaknesses: Preservation of a favourable soil structure needed through timely cultivation and careful irrigation at low watering rates. Application of P fertilisers is required for high yields.

Opportunities: High agricultural potential.

Threats: Wind erosion if allowed to dry out and water erosion on slopes following tillage.

Cryosols

Strengths: Carbon sink – permafrost and cryoturbation lock frozen organic matter in the soil.

Weaknesses: Frozen ground limits vegetation development. Collapse and subsidence due to thawing (thermokarst).

Opportunities: High ecological and environmental value.

Threats: Warming climate will lead to thawing. Already very limited extent in Africa.

Durisols

Strengths: Many Durisols in southern Africa are excellent for vine-growing.

Weaknesses: Their use is fairly restricted once a pan has developed.

Opportunities: Only after breaking up the pan, and with irrigation they can be successfully be planted with crops.

Threats: Crust development can hamper cultivation.

Ferralsols

Strengths: Sustain natural vegetation – commonly under tropical rainforest. Can sustain limited cultivation with addition of lime and fertilisers.

Weaknesses: Ferralsols require specific soil management. As both inherent nutrient levels and nutrient retention are low to very low, soil amendments have to be given in small portions. Some Ferralsols are so strongly weathered that they do not hold nutrients anymore. The strong micro-aggregation leads to loose packing of the aggregates and the dominance of large pores; consequently, most Ferralsols have a low water-retention capacity. During significant dry spells supplementary irrigation may be needed to prevent drought stress.

Opportunities: Although most Ferralsols are acidic and have a high aluminium saturation, actual amounts of exchangeable aluminium are low and can easily be corrected by liming. However, the high iron content results in the fixation phosphorus from fertilisers.

Threats: Maintaining soil fertility and prevention of surface soil erosion are important management requirements.

Fluvisols

Strengths: Fluvisols, except for the very acid ones, are fertile because of the regular supply of nutrients. Riverine Fluvisols are highly suitable for wetland rice because of the close proximity to fresh water.

Weaknesses: Flood control or drainage may be needed due to proximity of rivers. Low-lying backswamps, if not suitable for wetland rice, are best left under the natural vegetation; these areas may be used for extensive grazing when they are accessible.

Opportunities: High agricultural potential.

Threats: Flooding and waterlogging. Prone to urbanisation and sealing.

Gleysols

Strengths: Gleysols normally occur in level terrain. The proximity to groundwater makes them very suitable for growing wetland rice.

Weaknesses: Care is needed if large amounts of iron are present as this can lead to bronzing of the leaves and yield reduction. Most crops need to be drained and water levels in the soil need to be controlled.

Opportunities: Adequately drained Gleysols can be used for arable cropping, dairy farming and horticulture.

Threats: Waterlogging, lack of air for roots, compaction.

Gypsisols

Strengths: Can support limited extensive grazing.

Weaknesses: Gypsisols do not hold much water. Due to the presence of gypsum the soils have a high pH, normally over 8, which creates disorder in plant-available nutrients. The sandy nature, the alkaline character and the lack of water make most Gypsisols unsuitable for cropping. Moreover, when irrigated gypsum dissolves, water will easily seep through the soil and become unavailable to plants.

Opportunities: Limited. Cultivation possible on soils with relatively low gypsum content if irrigated.

Threats: When high amounts of gypsum are present, the soil structure may collapse under irrigation.

Histosols

Strengths: Contain more than 20% organic matter and have a high water content.

Weaknesses: Their bulk density is very low, some 0.4 kg dm^{-3} or less. Bearing capacity is very low. Nutrient imbalances are rampant and macronutrients such as calcium or magnesium are often lacking or occur only in very small quantities.

Opportunities: High ecological and environmental value – important store of terrestrial carbon.

Threats: When drained, they suffer from risk of fire, irreversible shrinkage and surface subsidence.

Kastanozems

Strengths: Kastanozems are highly fertile soils and therefore much sought after by farmers.

Weaknesses: They may suffer from nutrient imbalances because of the excess of calcium in the soil system. To make them productive during the dry, hot summer season, irrigation is necessary.

Opportunities: Kastanozems in the Mediterranean region are planted mainly with winter wheat during the rainy season.

Threats: When dry and under fallow conditions, the soil is susceptible to wind erosion; when situated on slopes the soil may suffer from water erosion under high-intensity rainfall.

Leptosols

Strengths: They provide a solid foundation for construction.

Weaknesses: Leptosols are unsuitable for growing crops. They have a limited rooting depth, a low water-holding capacity and their nutrient supply is confined to what is available in the shallow top layer.

Opportunities: Farmers use Leptosol areas only for grazing of their cattle.

Threats: Erosion

Lixisols

Strengths: Lixisols can be fairly productive. The low inherent fertility and nutrient-retention capacity dictate a split-application of necessary fertilisers, preferably close to the plants. Liming is not required.

Weaknesses: Occurring mainly in the dry savannah region with low biomass production, Lixisols do not hold much organic matter. Consequently, high-intensity rainfall will destroy any soil structure present.

Opportunities: Surface mulch during fallow periods will help prevent the development of a crust. As Lixisols mainly occur in the drier parts of Africa, irrigation may be needed to grow crops during the dry season or to overcome dry spells during the rainy season. The use of water traps is recommended to store as much rainwater as possible in the soil.

Threats: Like their acid counterparts the Acrisols, Lixisols are prone to erosion. If not protected, a crust may develop which prevents rain from entering the soil. Overland flow will then erode the topsoil which is the most fertile part. Also wind erosion may take its toll; loose soil particles on the surface can easily be blown away.

Luvisols

Strengths: Luvisols are productive soils, in northern Africa they are planted with winter wheat and vegetables under irrigation during summer. They have a large mineral nutrient reserve and a good aeration. Rooting depth is normally unlimited unless they overlie continuous hard rock or a petrified layer.

Weaknesses: Due to long and continued cultivation, in northern Africa since Roman times, most Luvisols have lost their topsoil; therefore they are poor in organic matter and nitrogen-deficiency is quite common.

Opportunities: Productive soils if managed appropriately.

Threats: Prone to erosion on slopes.

Nitisols

Strengths: Nitisols are suited for a wide range of crops. In eastern Africa many Nitisol areas are used to grow coffee.

Weaknesses: In annual cropping, fertiliser application is necessary to make these soils productive. Due to the high amount of active iron, Nitisols suffer from phosphate-fixation. Retention rates of 80% or more are common.

Opportunities: Intensive liming can overcome the aluminium toxicity.

Threats: Erosion on slopes.

Phaeozems

Strengths: Phaeozems are highly productive soils, provided rooting if not inhibited by continuous hard rock.

Weaknesses: Such soils may suffer from drought because the water-holding capacity is limited to the surface layer.

Opportunities: Good agricultural potential.

Threats: Drought, wind erosion.

Planosols

Strengths: Most areas with Planosols are best kept under natural vegetation, usually grassland; some are used for wetland rice.

Weaknesses: Because these soils are subject to frequent waterlogging, their use is limited.

Opportunities: Grasslands with supplemental irrigation in the dry season are a good land use in climates with long dry periods and short infrequent wet spells. Strongly developed Planosols with a very silty or sandy surface are best left untouched.

Threats: Waterlogging, wind erosion if allowed to dry out.

Plinthosols

Strengths: When still soft, the plinthite can be cut and dried to use as building stone. When it hardens as loose concretions, it can be used for road surfacing or airstrip construction.

Weaknesses: When cultivating Plinthosols, care must be taken that water levels do not drop below the depth where the iron-rich layer occurs.

Opportunities: Limited for agriculture. Plinthosols are a source of raw material as aggregate or ore deposit.

Threats: Plinthosols may also occur on slopes where groundwater comes close to the surface; in this position they must be protected from erosion.

Podzols

Strengths: Tropical Podzols normally sustain a light forest cover that recovers very slowly after cutting or burning.

Weaknesses: The low nutrient status, low level of available moisture and low pH make Podzols unattractive soils for arable farming.

Opportunities: Limited. Mature Podzols are generally best used for extensive grazing or left idle under their natural vegetation.

Threats: Lacking nutrients. Once left bare, vegetation may have great difficulties to re-establish itself.

Regosols

Strengths: Most Regosols are well supplied with nutrients as they occur in young weathering material.

Weaknesses: Water-holding capacity is often low and water stress of crops is common.

Opportunities: Shrub and tree cultivation where climate allows. Otherwise, best left under natural vegetation.

Threats: A weakly developed soil formation makes these soils prone to erosion.

Solonchaks

Strengths: Support natural habitats. Little agricultural value apart from extensive grazing.

Weaknesses: As salts are harmful to most crops, these soils are not directly suitable as farmland. When they dry out, the soil becomes very hard making land preparation, especially with hand tools, very difficult.

Opportunities: Cultivation possible only after salts have been flushed from the soil (which then ceases to be a Solonchak). Irrigation must satisfy the needs of the crop and maintain downward water flow to flush excess salts from the root zone.

Threats: Salinisation and wind erosion.

Solonetz

Strengths: Support natural habitats. Grazing.

Weaknesses: As high pH is harmful to most crops, these soils are not directly suitable as farmland. Land preparation becomes difficult when they dry out.

Opportunities: Can be improved if pH lowered or gypsum added.

Threats: Increased alkalinity and wind erosion.

Stagnosols

Strengths: Drained Stagnosols can be fertile owing to their moderate degree of leaching.

Weaknesses: Limited because of their oxygen deficiency and saturated status.

Opportunities: Can be improved by deep ploughing.

Threats: Climate change.

Technosols

Strengths: Can buffer toxic material and provide foundations for structures.

Weaknesses: Sealed by artificial surfaces and can contain toxic material – loss of soil functions, often total.

Opportunities: Limited unless greatly restored.

Threats: Loss of most soil functions.

Umbrisols

Strengths: Occurring in humid areas, suitable for woodland.

Weaknesses: Acidity.

Opportunities: Require heavy investment to make them productive. Natural acidity must be countered with lime.

Threats: Erosion risk for cultivation on slopes.

Vertisols

Strengths: Vertisols can be productive provided the right measures are taken.

Weaknesses: As most Vertisols occur in level areas water movement in the soil is limited and during wet periods water can stagnate on the surface. Heavy to work when wet. Swelling and shrinkage may destroy the foundation of structures (e.g. roads, irrigation canals).

Opportunities: Raised beds made out of the surface layer, which is often crumbly, are good seed beds as the water drains quickly into the adjacent furrows.

Threats: Can be susceptible to droughts.

A cultivated Bathiplinthic Ferralsol from Ghana. The distinct horizon occupying the uppermost 30 cm is a plough layer where the soil has been mixed by cultivation. Termite activity has created the distinct voids that are visible in the profile. A dark red nut-like nodule horizon (plinthite) is visible below a depth of 110 cm. (EM)

Africa's missing soil!

The WRB recognises 32 Reference Soil Groups, of which 31 are identified in this atlas. The missing group is Albeluvisols - soils with a thin, dark surface horizon on a bleached subsurface horizon that tongues into a horizon which has accumulated clay. The clay-rich horizon has an irregular or broken upper boundary resulting from the tonguing of bleached soil material into the subsoil. Albeluvisols are formed mostly in unconsolidated glacial till, lacustrine or fluvial materials on flat to undulating plains under coniferous forest or mixed forest in boreal and temperate climates with cold winters and short cool summers. The tonguing has a horizontal component similar to ice wedges which makes some suggest that their formation is indicative of a very cold, periglacial environment. Such conditions have been generally absent in Africa, which lacks glacial landscapes.

An Albeluvisol from southern Germany. The profile clearly shows a bleached topsoil with tounging onto the subsoil and polygonal patterns in the horizontal cross-section of the compacted subsoil. (EM)

An aerial view of termite mounds (also known as termitaria) on the Mozambique coastal plain. In savannah regions, such mounds are typically two to three metres high. Individual termite species may be identified by the shape of their mounds. Termites are responsible for significant soil mixing as a result of their burrowing and nest development. Note the associated vegetative growth due to the soil improvement actions of the insects. Soil surveyors use such features as proxies to denote changes in soil characteristics when preparing maps. Termite mounds act as islands of biodiversity in the savannah's. Birds use them as landing places, leave seeds of trees behind in their droppings which form fertile ground for germination. In this picture old termite mounds are fully encroached by savannah bush trees and shrubs, whereas the fresh mounds are bare. (MS)

Termites are significant in soil formation in tropical Africa. A highly organised and social group of insects, termites feed mostly on dead plant material, soil or animal dung. Some species of termite cultivate a specific species of fungi which can often be found in cavities in the soil. While termites can be regarded as a pest by some farmers, termites can have pronouced impact on soil characteristics. Termite activity can improve the soil structure by sorting soil particles, increase infiltration by improving porosity or decrease infiltration by producing compact surfaces which assist runoff and erosion. Other effects involve the chemical alteration of the soil, collecting and transporting organic matter to their nest structures and by increasing soil carbon and nutrient levels, especially nitrogen, phosphorus, potassium and exchangeable magnesium and calcium. (EVR)

Soil mapping in Africa

Collecting soil data. From left to right: Inspecting the boundary between the topsoil and subsoil in a road exposure in Tanzania (SD); the highly weathered nature of many sois in Africa require deep soil pits, as shown by this example from Ghana (EM); measuring soil pH in western Kenya (RMX). The status of regional soil survey in Africa is unsatisfactory given challenges such as food security, water scarcity, climate change and land degradation.

Soil survey or soil mapping is the process of identifying and delineating areas which have similar soil characteristics.

One of the key problems with mapping soil is that it is a continuum with gradual changes in characteristics over the landscape. Sometimes these changes occur over a few metres. More often, change occurs gradually and can only be recognised over long distances. Thus, boundaries between different types of soil or soil properties are often diffuse making it difficult to show true changes on a map, where sharp lines are drawn to separate one soil type from another.

Why map soils?

Soil mapping can be carried out for a number of purposes:

- To provide information to assist land and environmental management (e.g. for farmers) by identifying the natural capacity of the soil;
- To provide strategic information on the current status of soil quality (e.g. for national policy development);
- To provide a framework for extrapolating the results of local studies and soil monitoring networks;
- To demonstrate how local and national soil variability fits into the global pattern (trans-national policy).

The type or range of information required for each of these purposes is varied, although there is often overlap between them. Because of this, the techniques used to map soil and the information gathered during the survey can be very different, depending on the purpose of the mapping. In general there are two broad categories: General Purpose and Specific Purpose soil surveys. General Purpose surveys attempt to quantify and delineate a wide range of soil properties, most often associated with soil classes, so that they can be used for many different applications. General Purpose soil mapping tends to cover large areas ranging from individual river catchments to regions, countries or even continents. Specific Purpose surveys focus on quantifying the amount and spatial variation of a specific soil property or attribute. For example, the nutrient content, water-holding capacity and texture. Most Specific Purpose soil mapping is carried out within relatively small areas such as experimental plots or areas of land where a particular activity occurs or a specific incident may have contaminated the soil.

Soil mapping – current trends and the future

Since the 1980s, soil surveying has increasingly embraced a range of highly-sophisticated computer-based tools. The use of remote sensing technology (i.e. sensors and cameras mounted on aircraft and satellites), global positioning systems (GPS) to fix the information collected during fieldwork, hand-held tablets to log field observations and soil databases to store information are all now commonly employed by soil survey organisations. By using Geographic Information Systems (see page 136), all these data can be brought together in a single computing environment to speed up the production of soil maps in an accurate and precise manner. In the future, data from higher spectral and spatial resolution sensors, coupled with novel geo-statistical software, will be increasingly used to supplement information captured by traditional field surveys.

How are soil maps made?

Soil maps are based on field observations and interpretations of how and where the observed soil characteristics and associated soil types change between observation points. Such interpretation is based on conceptual models of how the local soil-forming factors and processes determine the variation of soil characteristics across the landscape. For most of the soil maps created during the previous century, these conceptual models were never explicitly defined or quantified, they were simply based on the experience of the soil surveyors and observations of local soil variation. With the advent of the digital age and Information Technology, these conceptual models are increasingly being quantified and made more consistent [64].

Field observations are the key to making good soil maps. The location of each inspection point is chosen by the field surveyor to provide information as to how the soil characteristics being mapped vary in relation to the local geology, landscape, vegetation and climate – all factors used to develop the conceptual model of soil spatial variation. Often, inspection points are located on a straight line that crosses the landscape where the topography (how slopes vary across the landscape creating different land forms) and geology vary the most. In other cases, where the landscape has little variation, inspection points are located more randomly. In some cases, particularly for national 'inventory' purposes, observation points are located at predetermined intervals on a standard grid, for example, at 10 km x 10 km.

At each inspection point, soil characteristics are examined either by digging a small pit to reveal a profile or by using an auger (a handheld screw drill) to extract soil samples. Both techniques normally sample to a depth of up to 2 m, less if bedrock is encountered. Each sample point is geo-referenced and the characteristics of the soil are entered onto recording sheets, often in the form of symbols or 'shorthand' notes.

In modern soil mapping, the information is entered either directly as digital data, or onto standardised forms which are then digitised. The information recorded for each horizon usually varies but generally includes the thickness, colour, texture, size and shape of soil structures, presence of carbonates, stones, etc. [65]. In addition, at a limited number of inspection points, soil samples are taken for more detailed laboratory analysis.

Once a number of field observations have been made, the field surveyor begins to develop a conceptual model of the relationships between soil characteristics and local topography, climate, parent material and land use. Tentative boundaries are sketched between different soil areas and the changes in soil characteristics between these boundaries are checked by further field observation. This process usually results in amendments being made to both the conceptual model used to interpolate between points and the boundaries placed on the field map sheets. By the end of the field survey, a set of field map sheets showing the boundaries between different soil areas will have been finalised.

Soil survey in Africa

Unfortunately, many African countries have very limited detailed mapping of their soil resources. What exists is of variable age and quality and only partly correlated with other countries. Most countries have a general soil map at very small scales, usually substantially smaller than 1:250 000. For many, the only national coverage is still the Soil Map of the World at a scale of 1:5 Million produced by the FAO and UNESCO in the 1970s. Detailed soil information for regional or project planning is usually not available. For example, only 15% of the DR Congo has been mapped at scales of 1:50 000 to 1:500 000.

The adjacent table shows the national coverage of soil maps of selected African countries, from which the following general conclusions may be drawn:

- Cartographic coverage for regional master planning of scales between 1:100 000 and 1:250 000 is largely incomplete, making it difficult to identify high-potential areas or, conversely, critical problem areas and their priority for more detailed inventories;
- Soil maps appropriate for project planning at scales around 1:25 000 cover very small areas;
- Soil maps suitable for operational planning, usually at scales larger than 1:25 000, are limited to specific projects.

	Small scale 1 : 500000 - ± 100000 (%)	Medium scale 1 : 100000 - ± 50000 (%)	Large scale 1 : 25000 (%)
Algeria	-	5	5
Benin	100	10	2
Botswana	40	5	-
Burkina Faso	100	25	-
Burundi	100	-	-
Cameroon	30	5	1
DR Congo	10	5	-
Egypt	100	10	10
Gabon	30	-	-
Gambia	100	-	100
Ghana	95	-	-
Kenya	100	25	-
Mali	50	-	-
Morocco	-	40	20
Nigeria	70	35	-
Rwanda	100	100	-
South Africa	70	-	-
Swaziland	100	10	5
Tanzania	50	-	-
Togo	80	20	-
Uganda	100	-	-

National soil survey coverage in selected African countries. [60]

SOTER

The SOil and TERrain (SOTER) methodology was developed by the FAO and ISRIC to provide a rapid update of the 1:5 Million Soil Map of the World. Existing soil maps and their associated information are converted into digital data to identify areas of land with a distinctive pattern of landform, lithology, surface form, slope, parent material and soil at scales of 1:1-2 million. SOTER data exist for Kenya, Northeastern Africa, Southern Africa, Central Africa, Senegal, The Gambia and Tunisia.

http://www.fao.org/nr/land/databasesinformation-systems/soter/it/

Legends

How does a legend work?

A legend explains the cartographic symbols used to construct a map and is intended to aid the understanding of the map content. Legends consist typically of a symbol or a series of symbols with specific colours or shades that are repeated on the map sheets in a consistent manner on all maps associated with the particular legend.

Construction of the legend

The 2006 version of the World Reference Base for Soil Resources (WRB) has been used to construct the legend of the soil maps in this atlas. The WRB recommends that the Reference Soil Group with a single prefix qualifier be used for small-scale maps (i.e. smaller than 1:1 million). This recommendation has been followed in the construction of the legend for this atlas with a few exceptions where key diagnostic information was lacking.

On this page, the Reference Soil Groups are listed alphabetically. The division within an individual Reference Soil Group follows the order of prefix qualifiers in the 2006 version of WRB (the same applies for the suffix qualifiers). A simple explanation of the main soil characteristic is presented on page 66.

For this atlas, the most prevalent soil type in each polygon is represented by a colour that corresponds to a specific WRB Reference Soil Group and a four-character code indicating the dominant characteristics of that soil (see pages 51 for a detailed descriptions of the specific soil characteristics). For example, the blue box that contains the code combination GLmo represents Mollic Gleysols on the soil maps which correspond to soils with a predominantly high water table for long periods of the year and have a nutrient- and organic rich, dark-coloured topsoil.

Cartographic symbols

International boundary	— — — —
Disputed boundary	- - - - - - - - - -
National capital	☐ ABUJA
Locality (by population)	
5,000,000 +	○ LAGOS
1,000,000 – 5,000,000	○ Abidjan
200,000 – 1,000,000	○ Nampula
100,000 – 200,000	○ Gweru

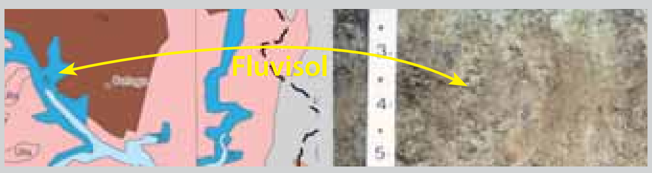
Soil Maps

The next section in the atlas contains a series of maps showing the regional distribution of WRB Reference Soil Groups across Africa.

As illustrated by the diagram below, a soil map depicts areas where soil properties, according to the classification scheme used, are similar. Hence, the light blue tones on the map correspond to the soil profile shown while the pink areas on the map correspond to a different soil type.

It is important to realise that a soil map is a two-dimensional representation of a three-dimensional object and that only the spatial or geographical change in soil properties is depicted.

Pages 64 - 66 present the legend to be used to interpret the regional maps while page 67 provides an index to the individual map sheets.



- Acrisols
- Alisols
- Andosols
- Arenosols
- Calcisols
- Cambisols
- Chernozems
- Cryosols
- Durisols
- Ferralsols
- Fluvisols
- Gleysols
- Gypsisols
- Histosols
- Kastanozems
- Leptosols
- Lixisols
- Luvisols
- Nitisols
- Phaeozems
- Planosols
- Plinthosols
- Podzols
- Regosols
- Solonchaks
- Solonetz
- Stagnosols
- Technosols
- Umbrisols
- Vertisols
- Water Body

Acrisols	
AC	Undifferentiated Acrisols
ACfr	Ferric Acrisols
ACha	Haplic Acrisols
ACpl	Plinthic Acrisols
ACum	Umbric Acrisols
Alisols	
ALgl	Gleyic Alisols
ALha	Haplic Alisols
ALpl	Plinthic Alisols
ALum	Umbric Alisols
Andosols	
ANsn	Silandic Andosols
ANvi	Vitric Andosols
ANzm	Mollic Silandic Andosols
ANzu	Umbric Silandic Andodols
Arenosols	
AR	Undifferentiated Arenosols
ARab	Albic Arenosols
ARbr	Brunic Arenosols
ARca	Calcaric Arenosols
ARfl	Ferralic Arenosols
ARha	Haplic Arenosols
ARpr	Protic Arenosols
ARwl	Hypoluvic Arenosols
Calcisols	
CLha	Haplic Calcisols
CLlv	Luvic Calcisols
CLpt	Petric Calcisols
CLzy	Haplic Calcisols (Yermic)
Cambisols	
CM	Undifferentiated Cambisols
CMca	Calcaric Cambisols
CMcr	Chromic Cambisols
CMdy	Dystric Cambisols
CMeu	Eutric Cambisols
CMfl	Ferralic Cambisols
CMgl	Gleyic Cambisols
CMvr	Vetric Cambisols
CMzt	Eutric Cambisols (Takyric)
CMzy	Eutric Cambisols (Yermic)
Chernozems	
CHcc	Calcic Chernozems
CHlv	Luvic Chernozems

Cryosols	
CR	Undifferentiated Cryosols

Durisols	
DU	Undifferentiated Durisols

Fluvisols	
FL	Undifferentiated Fluvisols
FLca	Calcaric Fluvisols
FLdy	Dystric Fluvisols
FLeu	Eutric Fluvisols
FLmo	Mollic Fluvisols
FLsz	Salic Fluvisols
FLti	Thionic Fluvisols
FLum	Umbric Fluvisols

Ferralsols	
FR	Undifferentiated Ferralsols
FRha	Haplic Ferralsols
FRpl	Plinthic Ferralsols
FRro	Rhodic Ferralsols
FRum	Umbric Ferralsols
FRxa	Xanthic Ferralsols

Gleysols	
GL	Undifferentiated Gleysols
GLcc	Calcic Gleysols
GLdy	Dystric Gleysols
GLeu	Eutric Gleysols
GLmo	Mollic Gleysols
GLum	Umbric Gleysols
GLza	Haplic Gleysols (Arenic)

Gypsisols	
GY	Undifferentiated Gypsisols
GYcc	Calcic Gypsisols
GYha	Haplic Gypsisols
GYhz	Haplic Gypsisols (Yermic)
GYpt	Petric Gypsisols

Histosols	
HSdy	Undifferentiated Histosols (Dystric)
HSeu	Undifferentiated Histosols (Eutric)
HSfi	Fibric Histosols
HSsa	Sapric Histosols

Kastanozems	
KS	Undifferentiated Kastanozems
KScc	Calcic Kastanozems
KSha	Haplic Kastanozems
KSlv	Luvic Kastanozems

Leptosols	
LP	Undifferentiated Leptosols
LPdy	Dystric Leptosols
LPeu	Eutric Leptosols
LPli	Lithic Leptosols
LPmo	Mollic Leptosols
LPrz	Rendzic Leptosols
LPum	Umbric Leptosols

Lixisols	
LX	Undifferentiated Lixisols
LXfr	Ferric Lixisols
LXgl	Gleyic Lixisols
LXha	Haplic Lixisols
LXpl	Plinthic Lixisols

Luvisols	
LV	Undifferentiated Luvisols
LVab	Albic Luvisols
LVcc	Calcic Luvisols
LVcr	Chromic Luvisols
LVfr	Ferric Luvisols
LVgl	Gleyic Luvisols
LVha	Haplic Luvisols
LVvr	Vertic Luvisols

Nitisols	
NT	Undifferentiated Nitisols
NTdy	Dystric Nitisols
NTeu	Eutric Nitisols
NTro	Rhodic Nitisols
NTum	Umbric Nitisols

Phaeozems	
PHgl	Gleyic Phaeozems
PHha	Haplic Phaeozems
PHlv	Luvic Phaeozems

Planosols	
PL	Undifferentiated Planosols
PLdy	Dystric Planosols
PLeu	Eutric Planosols
PLsc	Solodic Planosols
PLum	Umbric Planosols

Plinthosols	
PT	Undifferentiated Plinthosols
PTab	Albic Plinthosols
PTeu	Eutric Plinthosols
PTpt	Petric Plinthosols
PTpx	Pisoplinthic Plinthosols
PTum	Umbric Plinthosols

Podzols	
PZ	Undifferentiated Podzols
PZcb	Carbic Podzols
PZgl	Gleyic Podzols
PZha	Haplic Podzols

Regosols	
RG	Undifferentiated Regosols
RGca	Calcaric Regosols
RGdy	Dystric Regosols
RGeu	Eutric Regosols

Solonchaks	
SC	Undifferentiated Solonchaks
SCcc	Calcic Solonchaks
SCgl	Gleyic Solonchaks
SCha	Haplic Solonchaks
SCso	Sodic Solonchaks
SCzt	Haplic Solonchaks (Takyric)

Solonetz	
SN	Undifferentiated Solonetz
SNcc	Calcic Solonetz
SNgl	Gleyic Solonetz
SNha	Haplic Solonetz
SNmo	Mollic Solonetz
SNst	Stagnic Solonetz

Stagnosols	
STlv	Luvic Stagnosols
STlx	Lixic Stagnosols
STmo	Mollic Stagnosols

Technosols	
TC	Undifferentiated Technosols

Umbrisols	
UMcm	Cambic Umbrisols

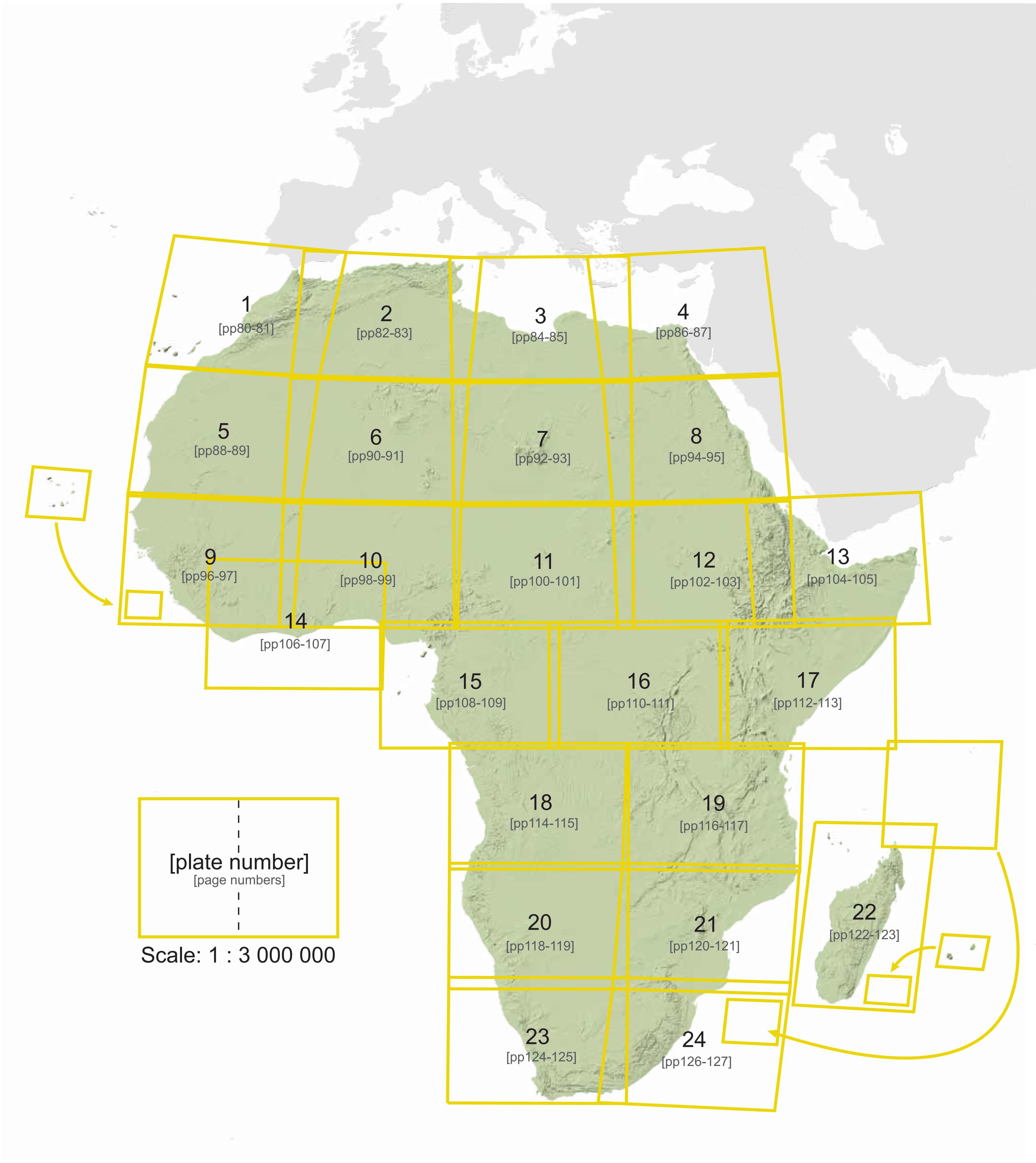
Vertisols	
VR	Undifferentiated Vertisols
VRcc	Calcic Vertisols
VRha	Haplic Vertisols
VRpe	Pellic Vertisols
VRzz	Haplic Vertisols (Mesotrophic)

Miscellaneous Categories	
	Water body

Alphabetical listing and brief description of legend codes

Code	Name	Description
AC	Undifferentiated Acrisols	– Very acid with a clay-rich subsoil
ACfr	Ferric Acrisols	– Very acid with a clay-rich subsoil but with distinct iron nodules
ACha	Haplic Acrisols	– Very acid with a clay-rich subsoil showing typical characteristics
ACpl	Plinthic Acrisols	– As AC with iron-rich, humus-poor, clay-rich horizon which hardens irreversibly
ACum	Umbric Acrisols	– As AC with thick, dark coloured, acid surface horizon, rich in organic matter
ALgl	Gleyic Alisols	– Very acid, clay rich subsoil and high nutrient-holding capacity, waterlogged conditions
ALha	Haplic Alisols	– Very acid, clay rich subsoil and high nutrient-holding capacity
ALpl	Plinthic Alisols	– As ALha with iron-rich, humus-poor, clay-rich subsurface horizon which hardens irreversibly
ALum	Umbric Alisols	– As ALha with thick, dark coloured, acid surface horizon, rich in organic matter
ANsn	Silandic Andosols	– Soil on volcanic material where allophane and similar minerals are predominant
ANvi	Vitric Andosols	– Soil containing volcanic glass
ANzm	Mollic Silandic Andosols	– As Ansn with dark coloured, acid surface horizon with moderate organic matter content
ANzu	Umbric Silandic Andodols	– As Ansn with thick, dark coloured, acid surface horizon, rich in organic matter
AR	Undifferentiated Arenosols	– Sandy soil
ARab	Albic Arenosols	– Sandy soil with pale coloured topsoil
ARbr	Brunic Arenosols	– Sandy soil with leached, reddish horizon
ARca	Calcaric Arenosols	– Sandy soil with notable levels of lime
ARfl	Ferralic Arenosols	– Sandy soil, intensely weathered with high levels of iron
ARha	Haplic Arenosols	– Sandy soil showing no major characteristics
ARpr	Protic Arenosol	– Sandy soil showing no horizon development
ARwl	Hypoluvic Arenosols	– Sandy soil with distinct clay accumulation
CHcc	Calcic Chernozems	– Deep, dark topsoil rich in organic matter with accumulation of calcium carbonate
CHlv	Luvic Chernozems	– Deep, dark topsoil rich in organic matter with clay-rich horizon
CLha	Haplic Calcisols	– Soil with significant accumulation of calcium carbonates
CLlv	Luvic Calcisols	– As CLha with clay-rich horizon
CLpt	Petric Calcisols	– As CLha having a strongly cemented or indurated layer
CLzy	Haplic Calcisols (Yermic)	– As CLha with rock fragments on the surface
CM	Undifferentiated Cambisols	– Moderately developed soil
CMca	Calcaric Cambisols	– Moderately developed soil with notable levels of lime
CMcr	Chromic Cambisols	– Moderately developed soil with a reddish hue
CMdy	Dystric Cambisols	– Moderately developed soil which is weathered, acid
CMeu	Eutric Cambisols	– Moderately developed soil which is not acid
CMfl	Ferralic Cambisols	– Moderately developed soil which is intensely weathered with low nutrient retention
CMgl	Gleyic Cambisols	– Moderately developed soil showing waterlogged conditions
CMvr	Vetric Cambisols	– Moderately developed soil with swelling clays
CMzt	Eutric Cambisols (Takyric)	– Moderately developed soil having a heavy textured surface horizon with surface crust
CMzy	Eutric Cambisols (Yermic)	– Moderately developed soil with rock fragments on the surface
CR	Undifferentiated Cryosols	– Soils affected by permanently frozen ground
DU	Undifferentiated Durisols	– Soil with significant accumulation of silica
FL	Undifferentiated Fluvisols	– Soil in floodplains, lakes, deltas or marine deposits
FLca	Calcaric Fluvisols	– Soil in floodplains, lakes, deltas or marine deposits with notable levels of lime
FLdy	Dystric Fluvisols	– Soil in floodplains, lakes, deltas or marine deposits, weathered, acid
FLeu	Eutric Fluvisols	– Soil in floodplains, lakes, deltas or marine deposits, not acid
FLmo	Mollic Fluvisols	– As FL with dark coloured, non-acid surface horizon with moderate to high organic matter content
FLsz	Salic Fluvisols	– As FL with a surface horizon containing a secondary enrichment of soluble salts
FLti	Thionic Fluvisols	– As FL with acid horizon rich in sulphur
FLum	Umbric Fluvisols	– As FL with thick, dark coloured, acid surface horizon, rich in organic matter
FR	Undifferentiated Ferralsols	– Strongly weathered soil with low nutrient levels
FRha	Haplic Ferralsols	– Strongly weathered soil with low nutrient levels showing no major characteristics
FRpl	Plinthic Ferralsols	– As FR with iron-rich, humus-poor, clay-rich horizon which hardens irreversibly
FRro	Rhodic Ferralsols	– Strongly weathered soil with low nutrient levels, very red
FRum	Umbric Ferralsols	– As FR with thick, dark coloured, acid surface horizon, rich in organic matter
FRxa	Xanthic Ferralsols	– As FR with low nutrient levels, yellow in colour
GL	Undifferentiated Gleysols	– Saturated by groundwater for long periods
GLcc	Calcic Gleysols	– As GL with accumulation of secondary calcium carbonate
GLdy	Dystric Gleysols	– Saturated by groundwater for long periods weathered, acid
GLeu	Eutric Gleysols	– Saturated by groundwater for long periods not acid
GLmo	Mollic Gleysols	– As GL with dark coloured, non-acid surface horizon with moderate to high organic matter content
GLum	Umbric Gleysols	– As GL with thick, dark coloured, acid surface horizon, rich in organic matter
GLza	Haplic Gleysols (Arenic)	– Saturated by groundwater for long periods having a loamy fine sand or coarser texture
GY	Undifferentiated Gypsisols	– High levels of gypsum
GYcc	Calcic Gypsisols	– High levels of gypsum with accumulation of secondary calcium carbonate
GYha	Haplic Gypsisols	– High levels of gypsum showing no major characteristics
GYhz	Haplic Gypsisols (Yermic)	– High levels of gypsum with rock fragments on the surface
GYpt	Petric Gypsisols	– High levels of gypsum having a strongly cemented or indurated layer
HSdy	Dystric Histosols	– Organic soil (peat), weathered, acid
HSeu	Eutric Histosols	– Organic soil (peat), not acid
HSfi	Fibric Histosols	– Organic soil (peat), having recognizable plant tissue
HSsa	Sapric Histosols	– Organic soil (peat) with very decomposed plant remains
KS	Undifferentiated Kastanozems	– Soil with an organic-rich surface horizon and calcium carbonate accumulation in the subsoil
KScc	Calcic Kastanozems	– As KS with accumulation of secondary calcium carbonate
KSha	Haplic Kastanozems	– As KS but showing no major characteristics
KSlv	Luvic Kastanozems	– As KS with clay-rich horizon
LP	Undifferentiated Leptosols	– Shallow soil over hard rock
LPdy	Dystric Leptosols	– Shallow soil over hard rockweathered, acid
LPeu	Eutric Leptosols	– Shallow soil over hard rock, not acid
LPli	Lithic Leptosols	– Shallow soil over hard rock having continuous rock close to the surface
LPmo	Mollic Leptosols	– As LP with dark coloured, non-acid surface horizon with moderate to high organic matter content
LPrz	Rendzic Leptosols	– As LP with dark, organic-rich acid surface horizon overlies calcaric materials
LPum	Umbric Leptosols	– As LP with thick, dark coloured, acid surface horizon, rich in organic matter
LV	Undifferentiated Luvisols	– Soil with clay accummulation in subsoil
LVab	Albic Luvisols	– Soil with clay accummulation in subsoil with pale top
LVcc	Calcic Luvisols	– As LV with accumulation of secondary calcium carbonate
LVcr	Chromic Luvisols	– As LV with a reddish hue
LVfr	Ferric Luvisols	– As LV but with distinct iron nodules
LVgl	Gleyic Luvisols	– As LV showing waterlogged conditions
LVha	Haplic Luvisols	– As LV showing no major characteristics
LVvr	Vertic Luvisols	– As LV with swelling clays
LX	Undifferentiated Lixisols	– Leached, slightly acid soil with a clay-enriched subsoil
LXfr	Ferric Lixisols	– As LX but with distinct iron nodules
LXgl	Gleyic Lixisols	– As LX showing waterlogged conditions
LXha	Haplic Lixisols	– As LX showing no major characteristics
LXpl	Plinthic Lixisols	– As LX with iron-rich, humus-poor, clay-rich horizon which hardens irreversibly on exposure
NT	Undifferentiated Nitisols	– Deep red with a well developed, nut-shaped structure
NTdy	Dystric Nitisols	– As NT, acid
NTeu	Eutric Nitisols	– As NT, not acid
NTro	Rhodic Nitisols	– As NT but very red
NTum	Umbric Nitisols	– As NT with thick, dark coloured, acid surface horizon, rich in organic matter
PHgl	Gleyic Phaeozems	– Slightly acid with a thick, dark-coloured surface layer showing waterlogged conditions
PHha	Haplic Phaeozems	– Slightly acid with a thick, dark-coloured surface layer showing no major characteristics
PHlv	Luvic Phaeozems	– Slightly acid with a thick, dark-coloured surface layer with clay-rich horizon
PL	Undifferentiated Planosols	– Poorly structured surface layer abruptly overlying a slowly permeable layer
PLdy	Dystric Planosols	– As PL, weathered, acid
PLeu	Eutric Planosols	– Poorly structured surface layer abruptly overlying a slowly permeable layer, not acid
PLsc	Solodic Planosols	– As PL having columnar or prismatic structure but lower sodium than Solonetz
PLum	Umbric Planosols	– As PL with thick, dark coloured, acid surface horizon, rich in organic matter
PT	Undifferentiated Plinthosols	– Soil with accumulation of iron that hardens irreversibly when exposed to air and sunlight
PTab	Albic Plinthosols	– As PT with pale top
PTeu	Eutric Plinthosols	– As PT, not acid
PTpt	Petric Plinthosols	– As PT having a strongly cemented or indurated layer
PTpx	Pisoplinthic Plinthosols	– As PT containing nodules that are strongly cemented with Fe
PTum	Umbric Plinthosols	– As PT with thick, dark coloured, acid surface horizon, rich in organic matter
PZ	Undifferentiated Podzols	– Acid soil with a bleached horizon underlain by an accumulation of organic matter, Al and Fe
PZcb	Carbic Podzols	– As PZ with dark coloured horizon of redeposited clay, organic matter and aluminium
PZgl	Gleyic Podzols	– As PZ showing waterlogged conditions
PZha	Haplic Podzols	– As PZ showing no major characteristics
RG	Undifferentiated Regosols	– Weakly developed soil in unconsolidated material
RGca	Calcaric Regosols	– Weakly developed soil in unconsolidated material with notable levels of lime
RGdy	Dystric Regosols	– Weakly developed soil in unconsolidated material weathered, acid
RGeu	Eutric Regosols	– Weakly developed soil in unconsolidated material not acid
SC	Undifferentiated Solonchaks	– Soil with accumulation of salt
SCcc	Calcic Solonchaks	– As SC with accummulation of secondary calcium carbonate
SCgl	Gleyic Solonchaks	– Soil with accumulation of salt showing waterlogged conditions
SCha	Haplic Solonchaks	– Soil with accumulation of salt showing no major characteristics
SCso	Sodic Solonchaks	– Soil with accumulation of salt, rich in sodium
SCzt	Haplic Solonchaks (Takyric)	– Soil with accumulation of salt having a heavy textured surface horizon and with surface crust
SN	Undifferentiated Solontez	– Soil with a clay accumulation horizon, rich in sodium
SNcc	Calcic Solontez	– As SN with accummulation of secondary calcium carbonate
SNgl	Gleyic Solontez	– As SN showing waterlogged conditions
SNha	Haplic Solontez	– As SN showing no major characteristics
SNmo	Mollic Solontez	– As SN with dark coloured, non-acid surface horizon with moderate to high organic matter content
SNst	Stagnic Solontez	– As SN showing waterlogged conditions at the surface
STlv	Luvic Stagnosols	– Soil with periodic water stagnation with clay-rich horizon
STlx	Lixic Stagnosols	– Soil with periodic water stagnation with clay-rich horizon
STmo	Mollic Stagnosols	– Periodic water stagnation, dark, non-acid surface horizon with moderate organic matter content
TC	Undifferentiated Technosols	– Soil that is sealed or contains a significant amount of artifacts
UMcm	Cambic Umbrisols	– Acid soils showing early development
VR	Undifferentiated Vertisols	– Soil with shrinking and swelling clays
VRcc	Calcic Vertisols	– As VR with accummulation of secondary calcium carbonate
VRha	Haplic Vertisols	– As VR showing no major characteristics
VRpe	Pellic Vertisols	– As VR, dark coloured
VRzz	Haplic Vertisols (Mesotrophic)	– As VR, slightly acid

Index to map sheets



The steps involved in the production of this map are described in pages 136-137. A digital version of the maps and an illustrative wall chart on the soils of Africa can be downloaded from:

http://eusoils.jrc.ec.europa.eu/library/maps/africa_atlas/index.html

Map scales

The scale of a map indicates how the size of the map relates to the size of the area on the ground. For example, one centimetre on a map with a scale of 1:100000 is equivalent to 1 kilometre on the ground.

Maps that are sufficiently detailed to show the positions of individual fields of a few hectares in size have scales from 1:5000 (1 cm : 50 m) to 1:25000 (1 cm : 250 m). Such maps are regarded as 'large scale'.

At a regional or national level, maps are more appropriate at medium scales, commonly 1:100000 (1 cm : 1 km) or 1:500000 (1 cm : 5 km).

Most of the maps shown in this atlas give a continental perspective and are based on maps compiled at scales smaller than 1:1000000 (1 cm : 10 km). Such maps are referred to as small scale.

The major soil types in Africa

The map shows the dominant WRB Reference Soil Groups for Africa. The map is a revised representation of the African part of the Digital Soil Map of the World produced by the Food and Agricultural Organization of the United Nations (FAO).

The map clearly shows the zonal arrangement of soils in Africa.

The central, wetter part is dominated by Ferralsols, depicted in brown-orange. They are associated with Acrisols (orange-brown). Towards drier parts, Lixisols start to appear (pale pink). In West Africa large areas of Plinthosols occur (dark brown), mainly as hardened surface layers or cuirasses.

The desert regions in the north and the south are dominated by Calcisols (bright yellow), Leptosols (shallow soils depicted in grey), Regosols (pale pink), Arenosols (brownish yellow) and Gypsisols (pale yellow). Very locally, especially in southern Africa, Durisols (pinkish grey) occur.

The dark purple colour on the map, mainly in Sudan and Ethiopia, indicate Vertisols whereas the bright red colours depict the dominance of Andosols, mostly associated with the African Rift valley. This is also where most of Africa's Nitisols are found (dark pink).

In the Mediterranean region pale brown and brown colours indicate areas of, respectively, Kastanozems and Phaeozems. Gleysols (blue) and Fluvisols (bright blue) are found throughout the map, the latter associated with Africa's river systems and deltas. Solonchaks (purple) and Solonetz (light purple) are mainly associated with coastal plains. Alisols (very pale yellow), Cambisols (orange), Histosols (dark grey), Luvisols (dark pink), Planosols (dark orange), Podzols (green) and Umbrisols (dark green) are scattered throughout the map and can be locally important.

In urbanised areas and near large mines, Technosols (highly disturbed soils) may occur. However, most of these areas will be too small to be visible at this continental scale.

Soil mapping unit

The soil mapping unit is the basic geographic component on the soil map. A soil type is a specific soil with definable characteristics. On large scale maps, the soil mapping unit corresponds to individual soil types.

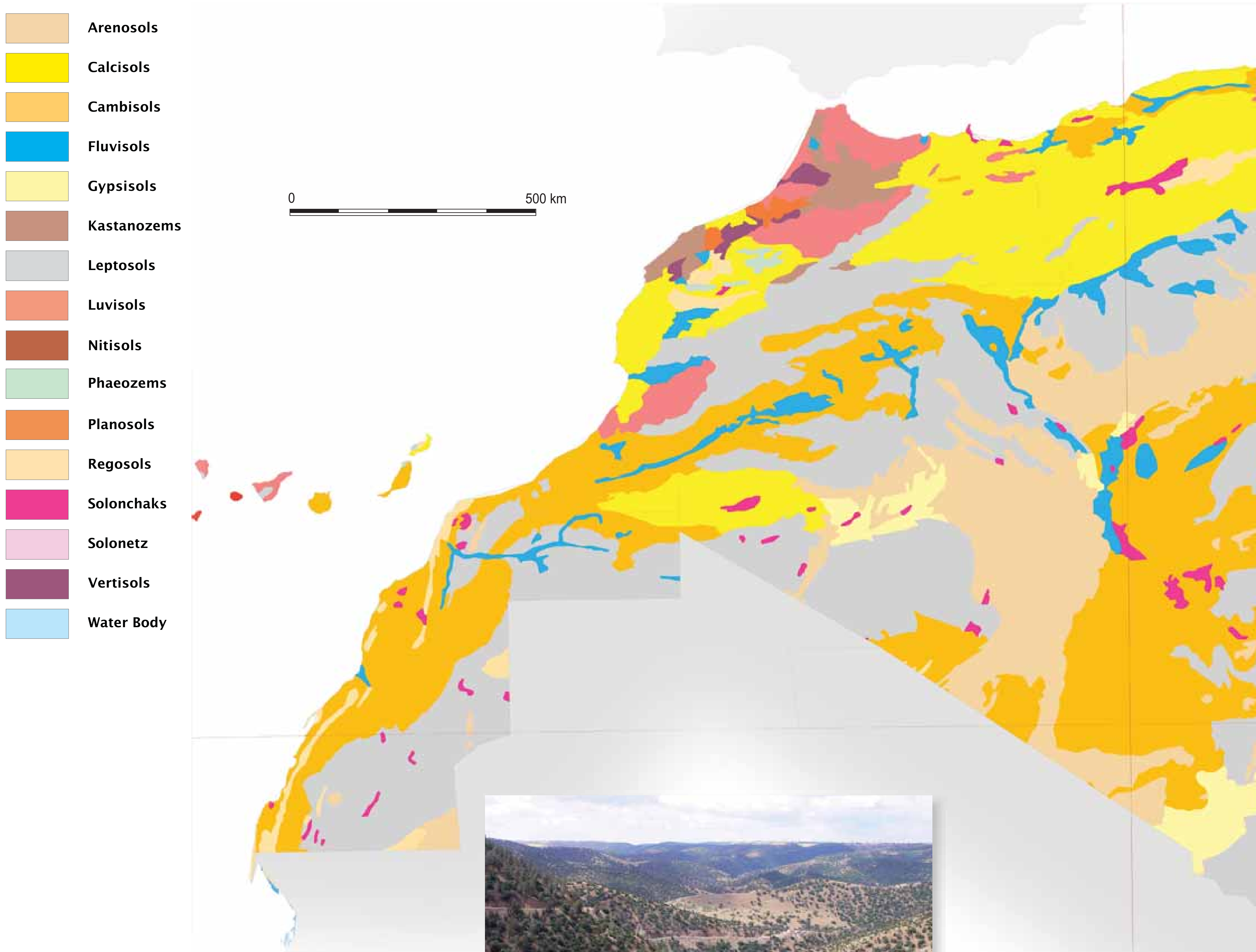
On small-scale maps, soil mapping units rarely comprise single soil types. Instead, they can consist of a combination of a dominant soil type with minor associated soils.

When the various soils of a soil mapping unit occur in a recognisable geographical pattern in defined proportions, they constitute a soil association. If such a pattern is absent, they form a soil complex. Soil associations merge into a mosaic to create a 'soilscape' or soil landscape unit.

In this context, if in the database a map unit is associated with 44% Gleyic Arenosols (sandy soils affected by shallow groundwater), 36% Lithic Leptosols (shallow stony soils) and 20% Albic Arenosols (sandy soils with a bleached topsoil), only the soil that occupies the largest areal extent is shown (i.e. the Gleyic Arenosols). If the assessment were to be based on Reference Soil Groups only, then 80% of the unit is covered by Arenosols. It should be stressed that in such a model, the location of the various soil types within the map unit is unknown at this scale of depiction.

Soils of the African Economic Community

The Arab Maghreb Union (AMU)



The Arab Maghreb Union (AMU - Union du Maghreb Arabe (UMA) in French) is an economic, social and cultural agreement to increase self-sufficiency and endogenous development while creating a framework for development and mobilisation of human resources and material between Algeria, Libya, Mauritania, Morocco and Tunisia (Egypt has applied to join). The AMU covers an area of 6 041 261 km^2 (around 20% of Africa) and has an estimated population of 92 million (2010) with a density of 15 people/km^2. Per capita Gross Domestic Produce (GDP) is estimated at US$ 4 229 [66]. According to UNEP, North Africa is the most urbanised region of Africa with an average urban population of 54%. In Libya, this rises to over 80%. Agriculture employs a significant proportion of the population (over 40% in Morocco). Where rainfall is more prevalent, cereals such as barley and wheat can be grown without irrigation. Olives, citrus fruits and wine grapes are also cultivated, largely with water supplied by artesian wells. Dates are common in the southern oases. However, drought is a recurring phenomenon in the region and causes sharp annual fluctuations in crop and livestock production.

The soils of the region reflect three broad divisions. Along the Mediterranean and Atlantic coasts, the climate is characterised by hot, dry summers and mild, wet winters. Natural vegetation takes the form of oak and pine woodlands, shrubs and grasses. The dry, hot summers make much of the region prone to fires. Cooler, more humid conditions are reflected by the presence of productive Kastanozems and Luvisols.

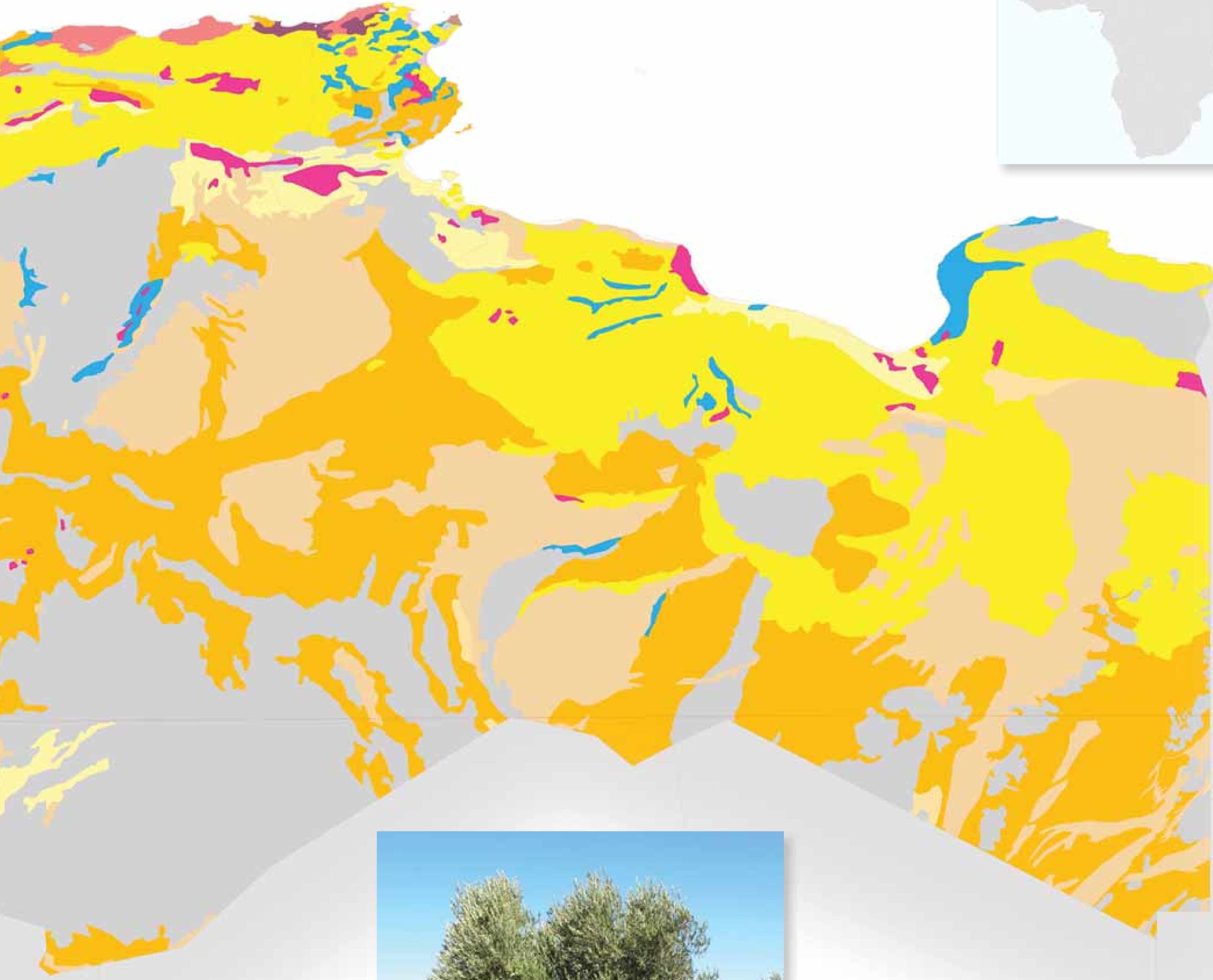
Outliers of the Atlas Mountains in central Morocco. (OS)

Away from the coast, the Atlas Mountains extend some 2 500 km through Morocco, Algeria, and Tunisia. The highest peak is Djebel Toubkal with an elevation of 4 167 m in southwestern Morocco. The Atlas Mountains separate the Mediterranean and Atlantic coastlines from the increasing aridity and temperatures of the Sahara Desert. The extent of the Atlas Mountains is clearly visible as a broad expanse of Leptosols and Cambisols.

The southern part of the region is characterised by the dry, desert soils of the Sahara. Calcisols, Gypsisols, Leptosols and Cambisols abound. The large sand seas (or ergs) are denoted by the Arenosols. Organic mater levels and water retention capacity are low for these soils while very saline Solonchaks can be found in depressions or in evaporate lakes (known locally as Chotts or Sebkhas). The blue linear features are Fluvisols, denoting river systems, many of which are ephemeral in nature (i.e. dry for much of the year).

The semi-arid conditions generally lead to poorly developed soils that are vulnerable to degradation by human activities such as overgrazing and erosion, especially by flash flooding after intense rainfall. Soil organic carbon levels are generally low or very low and desertification is key concern.

Leptosol over solid sandstone in central Morocco. Roots are restricted to the thin soil layer on top of the rock. (OS)



The above image shows an olive tree (*Olea europaea*) growing in a fertile, well drained soil in Morocco that develop originally under permanent grassland. Such soils, referred to as Kastanozems (from the Latin *castanea*, chestnut, and Russian *zemlja*, earth), develop organic-rich topsoils that provide essential plant nutrients while giving the soil a well defined structure and good water holding capacity. The presence of calcium carbonates makes the soil slightly alkaline. In between the olive trees, other food crops are cultivated. However, drought and maintaining soil organic matter levels are important considerations. (SH)

Sand seas occupy significant parts of the Sahara. The picture shows a Protic Arenosol in a dune deposit. The cross bedding throughout the profile indicates that wind is still playing an active role. Note the presence of sparse vegetation on the surface and buried cemented layers within the dune. (ISRIC)

Oasis with date palms in the heart of the Anti-Atlas in central Morocco. The oasis is filled with material washed down from its surroundings leaving the slopes bare. (OS)

The Economic Community of West African States (ECOWAS)

A red Lixisol from northern Ghana. A dark topsoil overlies a somewhat paler layer from which clay has been moved to the redder subsoil. (OS)

The Economic Community of West African States (ECOWAS - Communauté des Etats de l'Afrique de l'Ouest (CEDEAO) in French) is an economic, social and cultural agreement to increase self-sufficiency and endogenous development and create a framework for development and mobilisation of human resources and material between fifteen West African countries. Current members include Benin, Burkina Faso, Cape Verde, Côte d'Ivoire, The Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo. ECOWAS covers an area of 5 112 903 km^2 (around 17% of Africa) and has a population of around 300 million (2010) with a density of 49 people/km^2. Per capita GDP is estimated at US$ 2 500 [66].

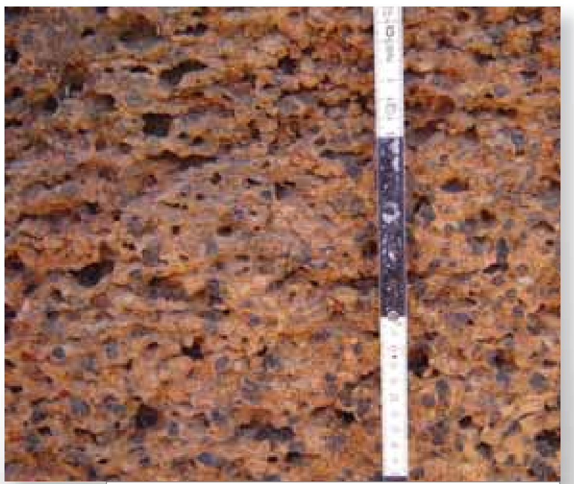
The ECOWAS area is bordered on one side by the deserts, on another side by the deciduous forest and tropical rainforest regions, and on a third side by the Atlantic Ocean. This is one of the most populated parts of Africa. Lagos in Nigeria has a population of around 8 million and is the second fastest growing city in Africa while Bamako in Mali has an annual growth rate of 4.45% and is the 6th fastest growing city in the world. A significant proportion of the population live in small villages and their main source of income is agriculture. Natural vegetation is generally open, ranging from sparse grassland to open-wooded grassland. Forests occur in more humid conditions. The climate has one or two pronounced dry seasons of several months. Rainfall varies from 300-1 000 mm per year.

To the north, the arid and hot desert conditions of the Sahara characterise the soil types: large expanses of sandy Arenosols are interspersed by Leptosols and Cambisols. Low soil organic matter levels, low water retention, over-grazing and drought makes wind erosion and desertification important considerations in these areas.

Lying between the Tropic of Capricorn and the Equator, the ECOWAS region displays the full range of tropical soil development. Ferralsols and Lixisols are dominant in association with Plithosols and acid Alisols and Acrisols. Despite their deep profile, good structure and drainage, the cultivation of tropical soils is problematic. The capacity of Ferralsols, Acrisols and Alisols to supply and retain nutrients for plants is very low. Very high rates of phosphate fertilisers and lime are required for significant yields. High levels of aluminium are also toxic for many plant species. Biological activity in the soil is low. The clay-rich subsoils of Lixisols have a slightly higher fertility but become quickly depleted under agricultural use. Plinthosols have low nutrient content and can harden irreversibly on exposure to air.

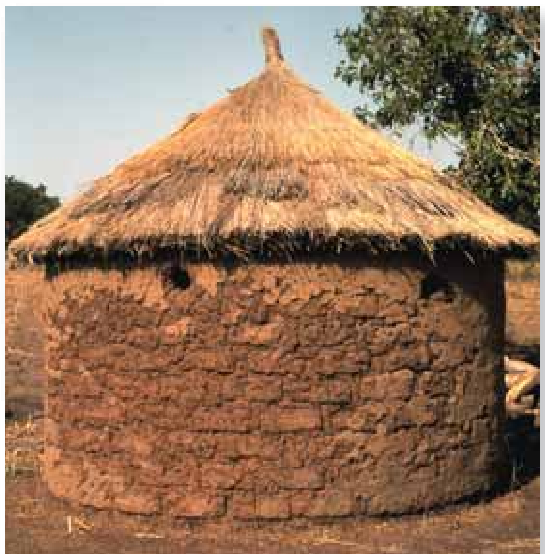
Fluvisols can be found in the mangrove areas along the coast and along the principle river valleys. Very evident is the Niger River, the principal river of west Africa and the third longest river in Africa. Over 4 080 km in length from its source in the Guinea Highlands, its drainage basin covers approximately 2 120 000 km^2 (about 6% of Africa). Gleysols denote both the Inner Niger Delta in Mali (important for agriculture and fishing) and the coastal delta in Nigeria.

Soil degradation due to land use change and desertification, together with the loss of soil nutrients, are the dominant soil issues in this area.

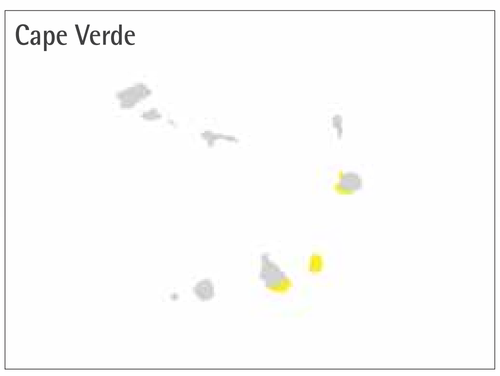


Detail of a strongly cemented petroplinthite horizon. The white material is kaoline (clay mineral) while the red is hematite (iron oxide) and the black patches are manganese nodules. (JD).

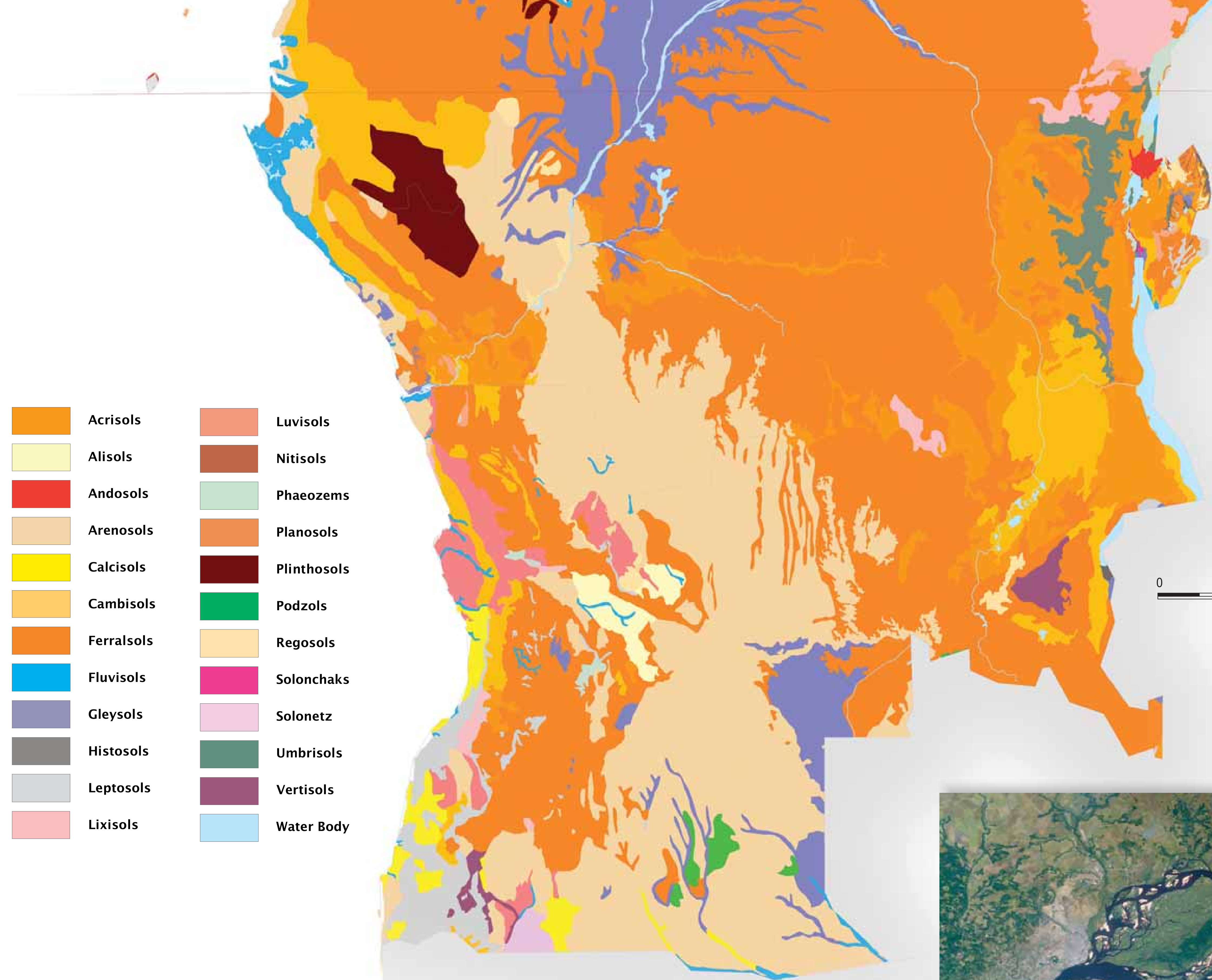
During the past 20 thousand years soil have developed in stabilised dunes that were once active in much drier climates. The photograph above shows a Ferralic Arenosol in the north of Burkina Faso. (MB/IRD)



Storage hut in Ghana built of hardened blocks of plinthite (also known as ironstone). The porous ironstone provides good isolation against the heat from outside. (OS)



Northern regions in the ECOWAS area are prone to land degradation. This photograph from Burkina Faso shows a stone bund in a field under sorghum cultivation to break and contain the flow of water over the surface of the soil. Such practices limit erosion and conserve soils. (RZ)



Satellite picture of Brazzaville, Kinshasa and the Malebo Pool of the Congo River. Also known as the Stanley Pool, the Malebo Pool is a lake-like widening in the lower reaches of the Congo River. About 35 km long, 23 km wide, its central part is occupied by M'Bamou or Bamu Island which has an area of 180 km². The pool is shallow with depths of 3 to 10 m. While water fluctuate vary by as much as 3 m, the shoreline is bounded by extensive palm and papyrus swamps while large floating mats of Eichhornia (water hyacinth) plants are prominent. (NASA)

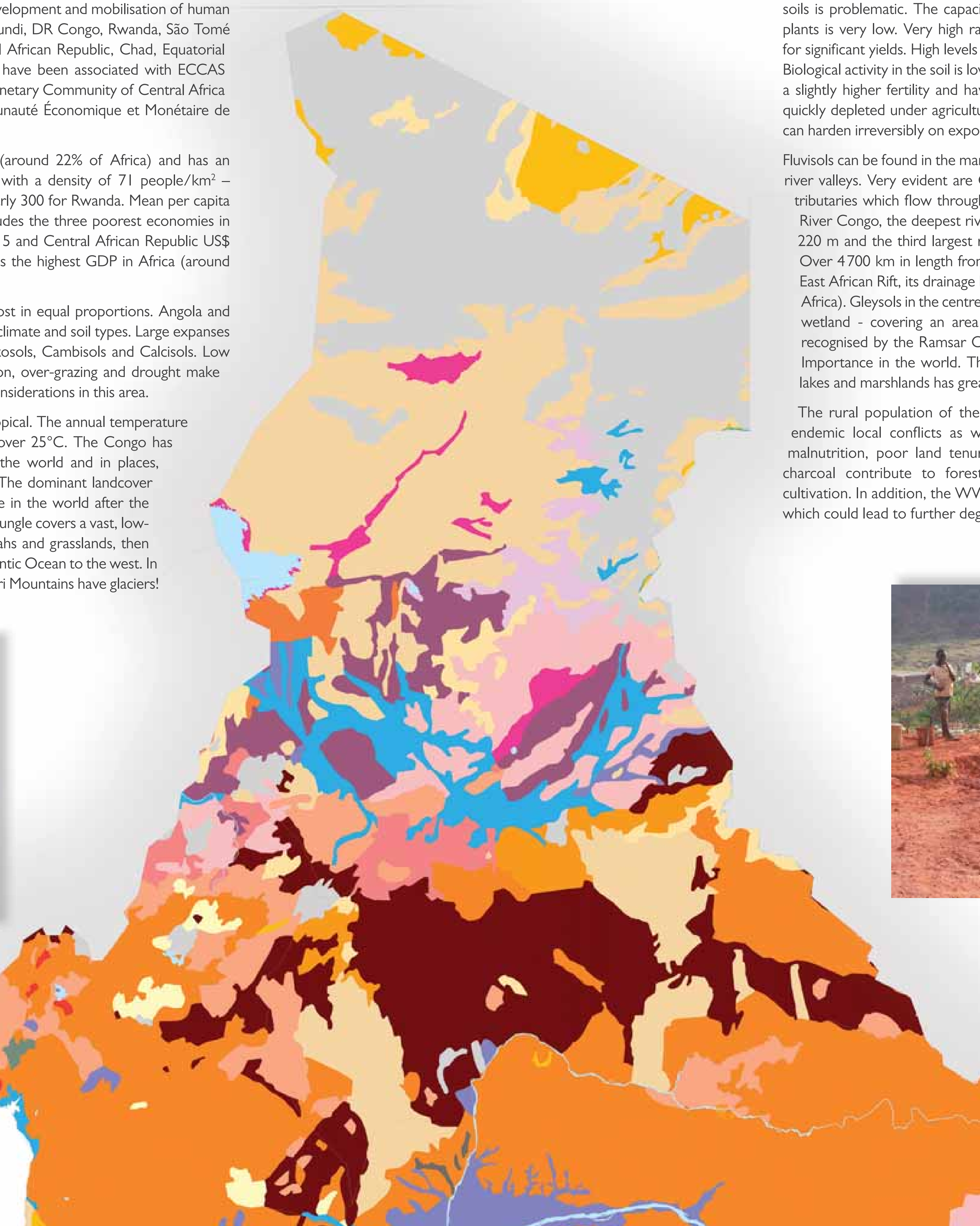
The Economic Community of Central African States (ECCAS)

The Economic Community of Central African States (ECCAS - Communauté Économique des États de l'Afrique Centrale (CEEAC) in French) is an economic, social and cultural agreement to increase self-sufficiency and endogenous development, and create a framework for development and mobilisation of human resources and material between Angola, Burundi, DR Congo, Rwanda, São Tomé and Príncipe. Since 2003, Cameroon, Central African Republic, Chad, Equatorial Guinea, Republic of the Congo and Gabon have been associated with ECCAS through an accord with the Economic and Monetary Community of Central Africa (or CEMAC from its French name - Communauté Économique et Monétaire de l'Afrique Centrale).

ECCAS covers an area of 6 667 421 km^2 (around 22% of Africa) and has an estimated population of 152 million (2012) with a density of 71 people/km^2 – although this ranges from 5 for Gabon to nearly 300 for Rwanda. Mean per capita GDP is estimated at US$ 2 500 but this includes the three poorest economies in Africa (DR Congo US$ 348, Burundi US$ 615 and Central African Republic US$ 768) and oil-rich Equatorial Guinea which has the highest GDP in Africa (around US$ 20 000). [66].

The ECCAS area straddles the Equator, almost in equal proportions. Angola and Chad are characterised by arid and semi-arid climate and soil types. Large expanses of sandy Arenosols are interspersed by Leptosols, Cambisols and Calcisols. Low soil organic matter levels, low water retention, over-grazing and drought make wind erosion and desertification important considerations in this area.

The climate is hot, humid tropical and sub-tropical. The annual temperature range is low and average temperatures are over 25°C. The Congo has the highest frequency of thunderstorms in the world and in places, annual rainfall can be more than 5 000 mm. The dominant landcover is tropical rainforest (the 2nd largest expanse in the world after the Amazon Basin). This massive expanse of lush jungle covers a vast, low-lying central basin which merges into savannahs and grasslands, then deserts to the north and south and by the Atlantic Ocean to the west. In the extreme east of DR Congo, the Ruwenzori Mountains have glaciers!



Climatic conditions, together with dense forest conditions, means that Ferralsols are the dominant soil type, often grading to Lixisols, Plinthosols, and Nitisols. Despite their deep profile, good structure and drainage, the cultivation of tropical soils is problematic. The capacity of Ferralsols to supply and retain nutrients for plants is very low. Very high rates of phosphate fertilisers and lime are required for significant yields. High levels of aluminium are also toxic for many plant species. Biological activity in the soil is low. The clay-rich subsoils of Lixisols and Nitisols give a slightly higher fertility and have reasonable water-holding capacity but become quickly depleted under agricultural use. Plinthosols have low nutrient content and can harden irreversibly on exposure to air.

Fluvisols can be found in the mangrove areas along the coast and along the principle river valleys. Very evident are Chad's major rivers - the Chari, Logone and their tributaries which flow through the southern savannahs into Lake Chad and the River Congo, the deepest river in the world with measured depths in excess of 220 m and the third largest river in the world by volume of water discharged. Over 4 700 km in length from its source in the highlands and mountains of the East African Rift, its drainage basin covers just over 4 000 000 km^2 (about 12% of Africa). Gleysols in the centre of the region denote the Tumba-Ngiri-Maindombe wetland - covering an area of 65 696 km^2 (twice the size of Belgium) and recognised by the Ramsar Convention as the largest Wetland of International Importance in the world. This vast area of forest and permanent or seasonal lakes and marshlands has great environmental and economic value.

The rural population of the region is extremely poor and many suffer from endemic local conflicts as well as food insecurity. High population growth, malnutrition, poor land tenure laws and unsustainable use of firewood and charcoal contribute to forest and soil degradation through slash-and-burn cultivation. In addition, the WWF report that rainfall has declined in recent years, which could lead to further degradation.

Brick making from a clay-rich soil in Cameroon. The bricks are then stacked and dried in the sun. The red colour indicates significant levels of iron or alumuinium oxides. Note the landslide on the slope in the background. (EM)

- Acrisols
- Alisols
- Andosols
- Arenosols
- Calcisols
- Cambisols
- Chernozems
- Cryosols
- Ferralsols
- Fluvisols
- Gleysols
- Gypsisols
- Histosols
- Leptosols
- Lixisols
- Luvisols
- Nitisols
- Phaeozems
- Planosols
- Plinthosols
- Podzols
- Regosols
- Solonchaks
- Solonetz
- Stagnosols
- Umbrisols
- Vertisols
- Water Body

Clayey Gleysol on a sandy deposit in the floodplain of the Zambezi River near Mongu, western Zambia. (RH)

Nitisol landscape from southern Ethiopia. (SDD)

Common Market for Eastern and Southern Africa (COMESA)

The Common Market for Eastern and Southern Africa (COMESA - Marché Commun de l'Afrique Orientale et Australe in French) is an economic, social and cultural agreement to increase self-sufficiency and endogenous development, and create a framework for development and mobilisation of human resources and material. It comprises Burundi, Comoros, Democratic Republic of the Congo, Djibouti, Egypt, Eritrea, Ethiopia, Kenya, Libya, Madagascar, Malawi, Mauritius, Rwanda, Seychelles, South Sudan, Sudan, Swaziland, Uganda, Zambia and Zimbabwe. COMESA covers an area of 13 million km^2 (over 40% of Africa) with an estimated population of over 405 million (2012). Mean per capita GDP is estimated at US$ 1 900. [66]

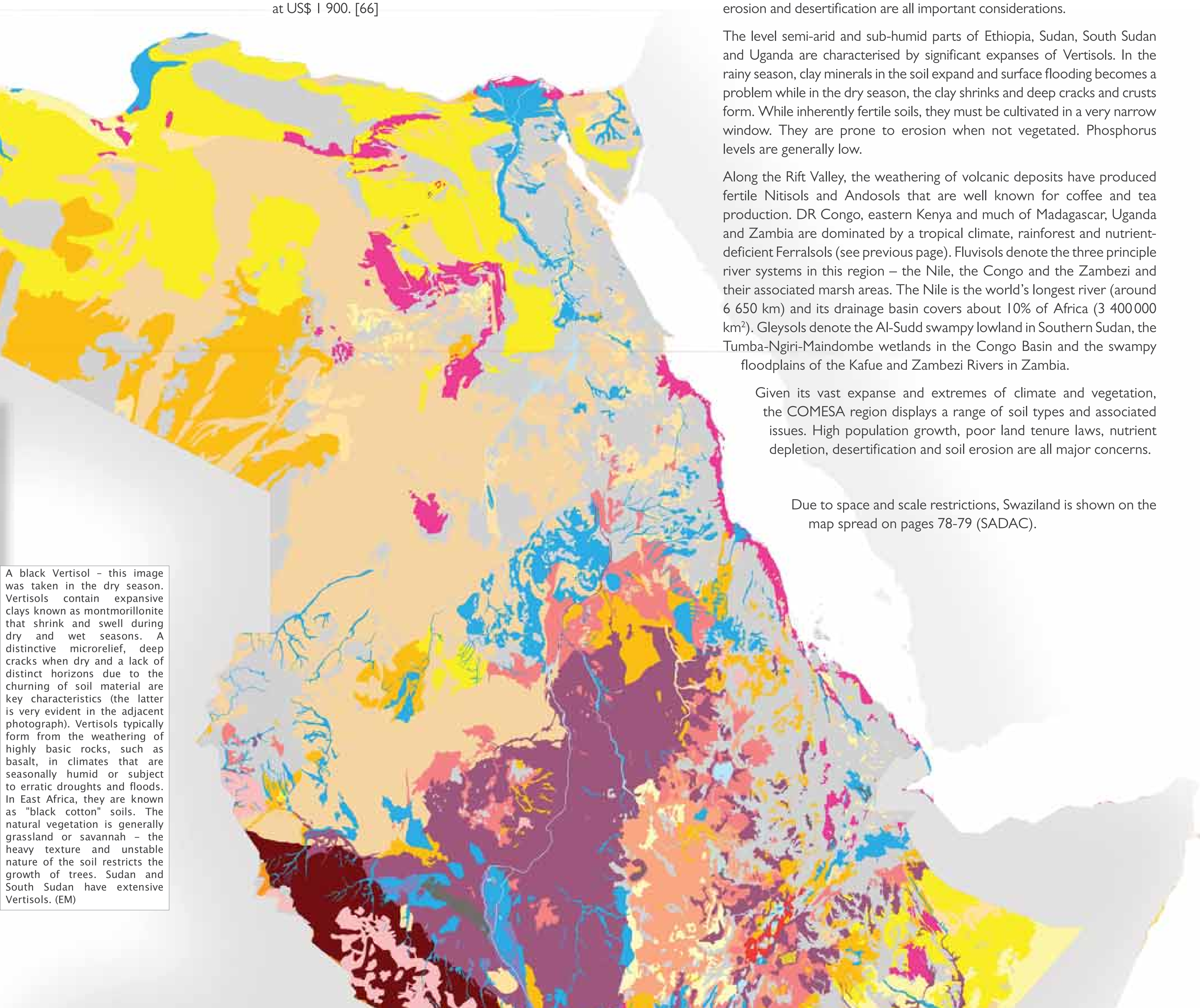
The COMESA area is enormous: stretching from Libya to Zimbabwe, it covers almost the entire eastern half of the continent. Egypt, Eritrea, eastern Ethiopia, eastern Kenya, Libya, Sudan and much of Zambia and Zimbabwe are characterised by arid and semi-arid climate and soil types. Large expanses of thin, stony Leptosols, sandy Arenosols and lime-rich Calcisols dominate these regions. Saline Solonchaks occur in depressions or on salt-rich parent material. The main impediment to the use of these soils is excessive levels of lime and soluble salts, combined with a scarcity of water. Where water is available, clay-rich Luvisols and Phaeozems can be very productive. Low soil organic matter levels, low water retention, over-grazing, drought, wind erosion and desertification are all important considerations.

The level semi-arid and sub-humid parts of Ethiopia, Sudan, South Sudan and Uganda are characterised by significant expanses of Vertisols. In the rainy season, clay minerals in the soil expand and surface flooding becomes a problem while in the dry season, the clay shrinks and deep cracks and crusts form. While inherently fertile soils, they must be cultivated in a very narrow window. They are prone to erosion when not vegetated. Phosphorus levels are generally low.

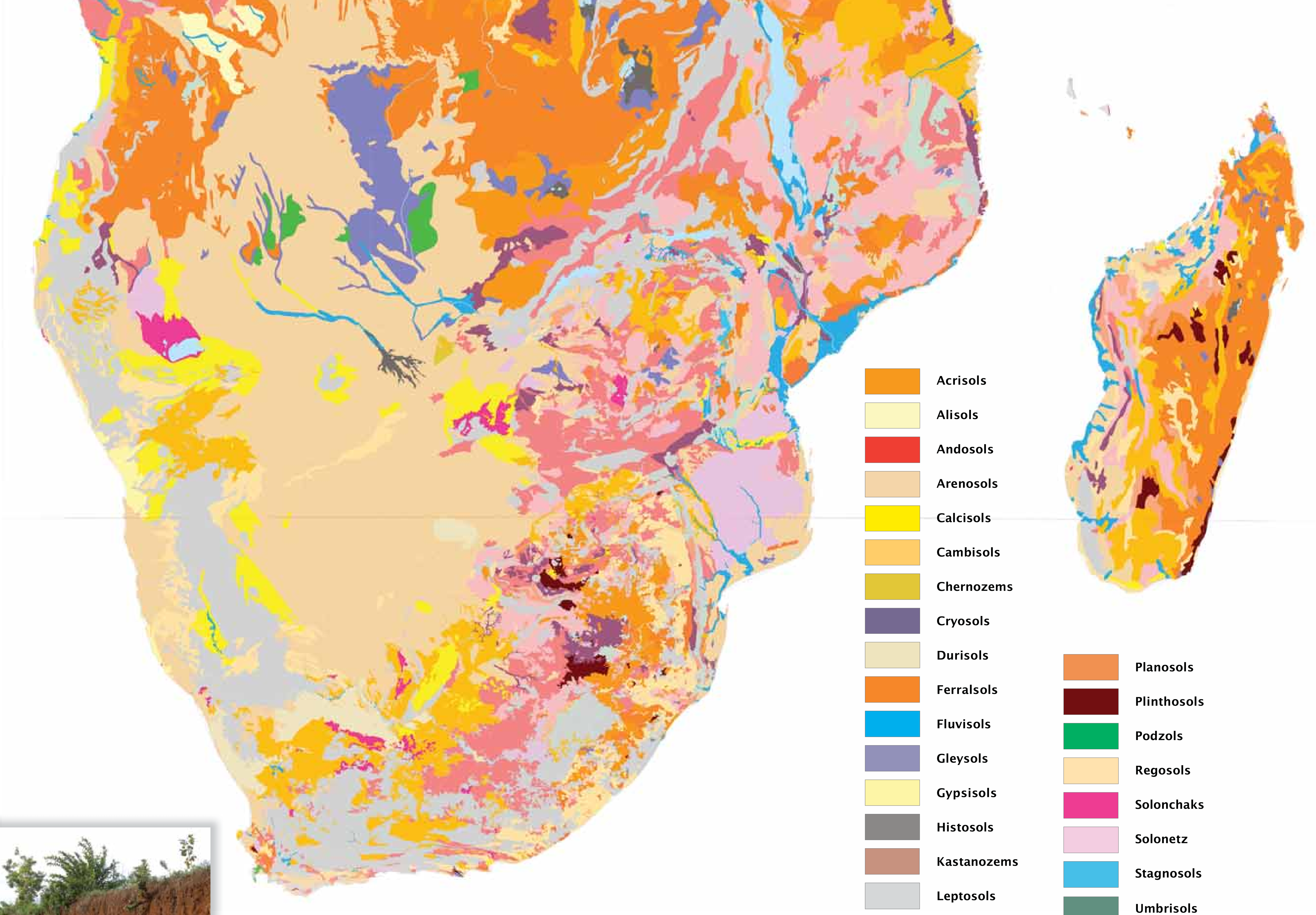
Along the Rift Valley, the weathering of volcanic deposits have produced fertile Nitisols and Andosols that are well known for coffee and tea production. DR Congo, eastern Kenya and much of Madagascar, Uganda and Zambia are dominated by a tropical climate, rainforest and nutrient-deficient Ferralsols (see previous page). Fluvisols denote the three principle river systems in this region – the Nile, the Congo and the Zambezi and their associated marsh areas. The Nile is the world's longest river (around 6 650 km) and its drainage basin covers about 10% of Africa (3 400 000 km^2). Gleysols denote the Al-Sudd swampy lowland in Southern Sudan, the Tumba-Ngiri-Maindombe wetlands in the Congo Basin and the swampy floodplains of the Kafue and Zambezi Rivers in Zambia.

Given its vast expanse and extremes of climate and vegetation, the COMESA region displays a range of soil types and associated issues. High population growth, poor land tenure laws, nutrient depletion, desertification and soil erosion are all major concerns.

Due to space and scale restrictions, Swaziland is shown on the map spread on pages 78-79 (SADAC).



A black Vertisol - this image was taken in the dry season. Vertisols contain expansive clays known as montmorillonite that shrink and swell during dry and wet seasons. A distinctive microrelief, deep cracks when dry and a lack of distinct horizons due to the churning of soil material are key characteristics (the latter is very evident in the adjacent photograph). Vertisols typically form from the weathering of highly basic rocks, such as basalt, in climates that are seasonally humid or subject to erratic droughts and floods. In East Africa, they are known as "black cotton" soils. The natural vegetation is generally grassland or savannah - the heavy texture and unstable nature of the soil restricts the growth of trees. Sudan and South Sudan have extensive Vertisols. (EM)



Red Ferralsol exposed in a road cut in Tanzania. (EM)

The Southern African Development Community (SADC)

The Southern African Development Community (SADC - Communauté Économique des États de l'Afrique Centrale (CEEAC) in French) is an economic, social and cultural agreement to increase self-sufficiency and endogenous development, and create a framework for development and mobilisation of human resources and material between fifteen southern African countries. The member states are Angola, Botswana, the Democratic Republic of the Congo, Lesotho, Malawi, Madagascar, Mauritius, Mozambique, Namibia, the Seychelles, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe. SADC covers an area of 10 million km^2 (around 32% of Africa) and has an estimated population of 240 million (2010) with a density of around 30 people/km^2 – however, this reflects a range of around 2 people/km^2 in Namibia to over 600 people/km^2 in Mauritius. There has been notable population growth in Malawi and Mozambique. Per capita GDP is estimated at US$ 3 152 – with South Africa being the economic powerhouse of the region [66]. The FAO has reported that agriculture supports about 85% of the rural population and employs 80% of the labour force. Rural poverty, unsustainable development and land tenure issues are the main causes and consequences of environmental degradation throughout the region.

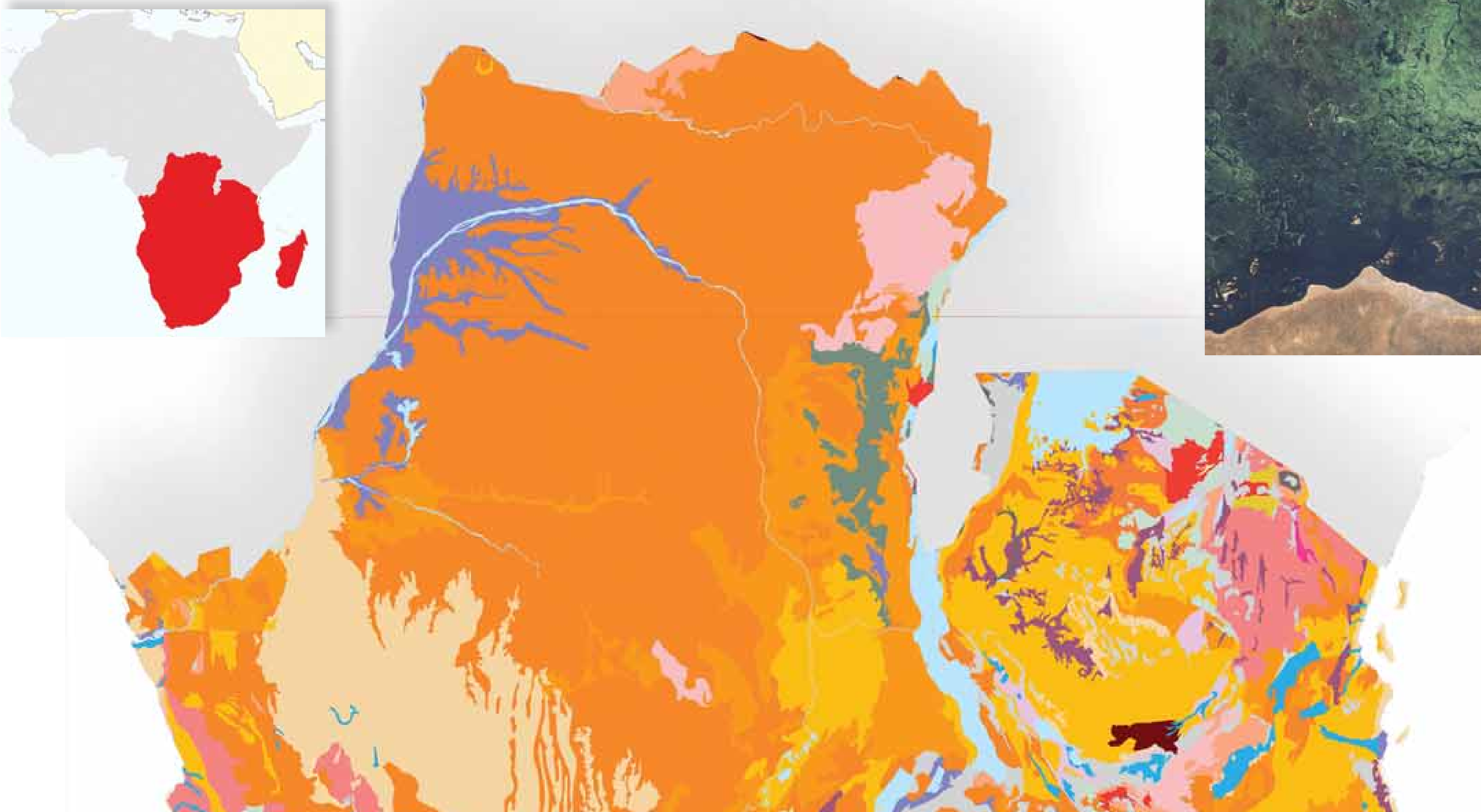
The SADC area is bordered on three sides by the seas of the Atlantic and Indian Oceans, while the north is characterised by tropical rainforest and savannah. Consequently, a broad range of soil types are to be found. The western half of the region is dominated by the Kalahari and Namib Deserts. The arid and hot conditions give rise to characteristic soil types. The Namib consists of sand seas (Arenosols) near the coast with gravel plains and scattered mountain outcrops further inland (Leptosols). Some of the sand dunes are 300 m high. Arenosols are interspersed by Leptosols and Cambisols. Unlike the Namib, the Arenosols of the Kalahari support grasses, acacia trees and salt-tolerant vegetation. As in the Sahara, low soil organic matter levels, low water retention, over-grazing and wind erosion are important considerations in this area.

In the more temperate and more humid southern and eastern parts, a mosaic of leached, red Acrisols, clay-rich Luvisols and stony Leptosols are mixed with Plinthosols, Vertisols and weakly developed Cambisols and Regosols. In general, the soils of southern Africa are not characterised by high fertility with water retention and availability being an issue (the fertile soils of the Western Cape river valleys and on the KwaZulu-Natal coast are exceptions). High concentrations of salts give rise to saline and sodic Solonchaks and Solonetz throughout Botswana, southern Mozambique, South Africa and Zimbabwe. Lightly leached, clay-rich Luvisols, interspersed with Ferralsols and Leptosols, dominate Malawi, northern Mozambique, southern Tanzania and eastern Zambia, with young Cambisols becoming more prevalent in northern Tanzania. Along the Rift Valley, volcanic soils are common and are intensively cultivated. The volcano of Kilimanjaro, the highest mountain in Africa, sits on the northern border of Tanzania.

Western Angola, DR Congo and much of Zambia are dominated by tropical Ferralsols under rainforest (see page 75). While the region is home to the Congo and Limpopo river basins and several large lakes (e.g. Lake Victoria - Africa's largest lake by area and the largest tropical lake in the world), the huge delta of the Limpopo is highlighted as a large expanse of Fluvisols.

The large expanse of Gleysols on the Angola/Zambia border denotes the Barotse wetlands in the Zambezi floodplain. Almost due south in Botswana are the peatlands of the Okavango Delta.

Key issues affecting soils in the SADC region are restricted water-holding capacity, soil erosion and surface crusting, large expanses of inherently saline, acid and/or nutrient poor soils and droughts in combination with organic matter and nutrient depletion through unsustainable cultivation practices.



The large expanse of Gleysols in the centre of the adjacent map denotes the swampy wetlands that are the source of the Zambezi, one of Africa's greatest rivers. The image above was acquired by a sensor onboard NASA's Earth Observing-1 (EO-1) satellite and shows a flood on the eastern tip of the Caprivi Strip in 2010. This striking true-color image shows the stark boundary between the southern and eastern edge of the floodplain (which is higher land and dry) while to the north, the land is flooded. Deep blue channels wind among green, shallowly flooded plains. This area corresponds to the zone of Fluvisols on the borders of the Caprivi Strip with Botswana, Zambia and Zimbabwe. (NASA)

This map shows the soils of Morocco and western Algeria. The major landscape feature in this region is the Atlas Mountain range that separates the slightly wetter and cooler Mediterranean area from the arid and hot Sahara Desert. The mountains manifest themselves as a band of stony Leptosols and weakly developed Cambisols running NE-SW across the map. Along the coasts, a Mediterranean climate, with mild wet winters and hot dry summers, prevails. While the higher regions of the western part of the Atlas Range can receive more than 2 000 mm of precipitation annually (even snow can fall on the peaks of the High Atlas), moisture levels generally decrease away from the coast.

Beyond the Atlas, semi-arid conditions quickly grade into desert, where daily temperatures can rise above 40°C. In more humid mountainous areas, extensive oak and conifer forests occur. At lower elevations, intensive clearance and grazing have produced a distinctive scrubby landscape known as macquis. There is little natural vegetation in the arid desert areas although the date palm is extensively cultivated in the desert oases.

The more humid climate of NW Morocco gives rise to more vegetation and more developed, clay-rich fertile soils such Kastanozems and Luvisols. Pockets of swelling and shrinking Vertisols are evident throughout the landscape. These soils support extensive cereal cultivation in the winter and grazing in the summer. Soils with high levels of calcium carbonate (Calcisols) are very evident, especially in drier conditions.

To the south of the Atlas Mountains, conditions are much more arid and daytime temperatures are significantly higher. Soils are characterised by minimal development and low or negligible organic matter content. Regosols, stony Leptosols and soils with 'fossilised' accumulations of gypsum (Gypsisols) dominate. Arenosols denote the locations of large sand seas and dunes. Saline soils occur in depressions along the coast and as dry lakes in the desert.

The blue linear features are Fluvisols, demarcating river systems in the region. Many are ephemeral in nature (i.e. dry for much of the year).

Where the soils have a well-developed structure and moderate levels of organic matter and water is available, many Mediterranean soils are quite productive. However, excessive lime and the presence of salts can be problematic. Away from the coast, the increasing semi-arid conditions generally lead to poorly developed soils that are vulnerable to degradation by human activities such as overgrazing which can lead to erosion, especially by flash flooding after intense rainfall. Soil organic carbon levels are generally low or very low and droughts are common. Desertification is a key concern throughout the region.

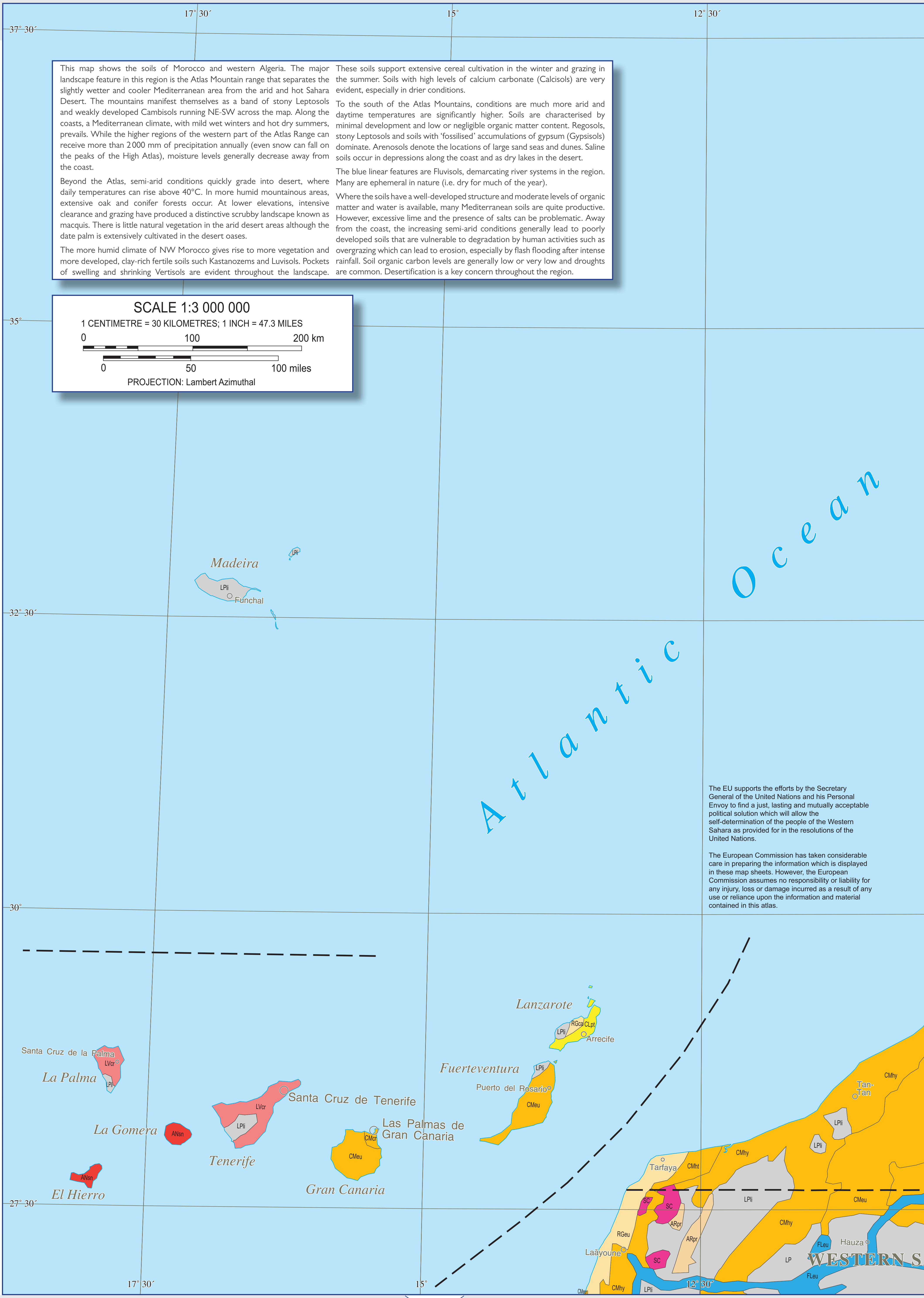
SCALE 1:3 000 000

1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES

0 100 200 km

0 50 100 miles

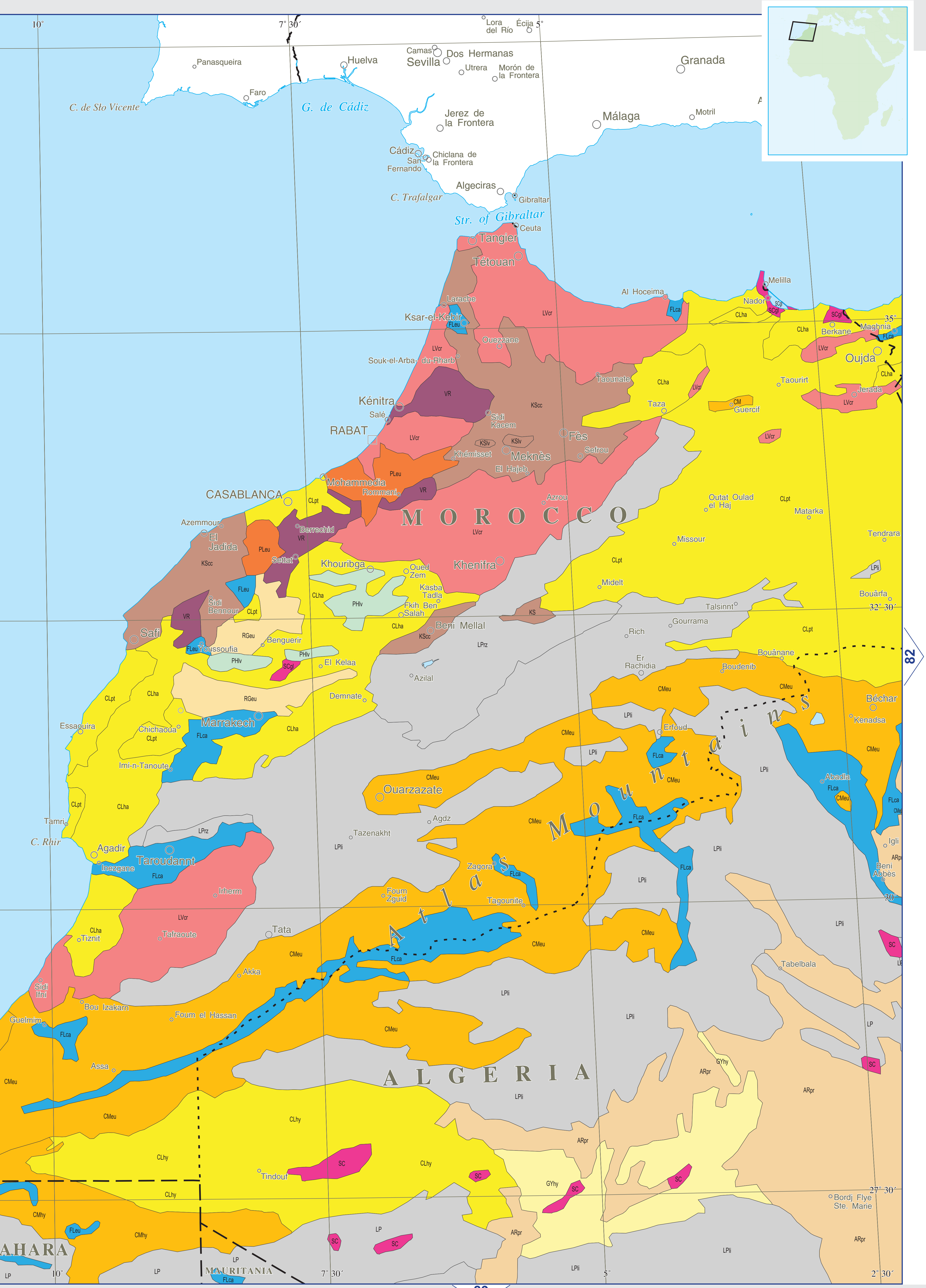
PROJECTION: Lambert Azimuthal



The EU supports the efforts by the Secretary General of the United Nations and his Personal Envoy to find a just, lasting and mutually acceptable political solution which will allow the self-determination of the people of the Western Sahara as provided for in the resolutions of the United Nations.

The European Commission has taken considerable care in preparing the information which is displayed in these map sheets. However, the European Commission assumes no responsibility or liability for any injury, loss or damage incurred as a result of any use or reliance upon the information and material contained in this atlas.

88



10°
7° 30´
5°
Lora del Río
Écija
Panasqueira
Huelva
Camas
Sevilla
Dos Hermanas
Utrera
Morón de la Frontera
Granada
Faro
C. de São Vicente
G. de Cádiz
Jerez de la Frontera
Málaga
Motril
Cádiz
San Fernando
Chiclana de la Frontera
Algeciras
C. Trafalgar
Gibraltar
Str. of Gibraltar
Ceuta
Tangier
Tétouan
Al Hoceima
Melilla
Nador
Larache
Ksar-el-Kebir
Ouezzane
Souk-el-Arba-du-Rharb
Berkane
Maghnia
35°
Oujda
Taourirt
Jerada
Taounate
Taza
Guercif
Kénitra
Salé
RABAT
Sidi Kacem
Fès
Sefrou
Khémisset
Meknès
El Hajeb
Mohammedia
Rommani
CASABLANCA
Azrou
MOROCCO
Outat Oulad el Haj
Matarka
Azemmour
El Jadida
Berrechid
Settat
Missour
Tendrara
Khouribga
Oued Zem
Khenifra
Kasba Tadla
Fkih Ben Salah
Midelt
Bouârfa
Sidi Bennour
Talsinnt
32° 30´
Safi
Beni Mellal
Gourrama
Youssoufia
Benguerir
Rich
El Kelaa
Er Rachidia
Bouânane
Boudenib
Azilal
Demnate
Béchar
Kenadsa
Essaouira
Chichaoua
Marrakech
Erfoud
Imi-n-Tanoute
Ouarzazate
Abadla
Agdz
Tazenakht
Atlas Mountains
Tamri
C. Rhir
Agadir
Taroudannt
Inezgane
Igli
Beni Abbes
Irherm
Zagora
Foum Zguid
Tagounite
30°
Tiznit
Tafraoute
Tata
Akka
Tabelbala
Sidi Ifni
Bou Izakarn
Guelmim
Foum el Hassan
Assa
ALGERIA
Tindouf
27° 30´
Bordj Flye Ste. Marie
SAHARA
MAURITANIA
2° 30´
82
89

This map shows the soils of eastern Morocco, northern Algeria, Tunisia and western Libya. The major landscape features in this region are the Atlas Mountain range and the hot and arid Sahara Desert. The mountains manifest themselves as a band of stony Leptosols running NE-SW across the map, decreasing in elevation towards the east. Along the coast, a Mediterranean climate, with mild wet winters and hot dry summers, prevails. However, precipitation decreases away from the coast. In the west, the southern edge of the Atlas denotes the beginning of the Sahara Desert where semi-arid conditions quickly grade into desert (daily temperatures can rise above 40°C, rainfall is irregular). To the east, the lack of elevation makes conditions hotter and drier. In more humid mountainous areas, extensive oak and conifer forests occur. At lower elevations, intensive clearance and grazing have produced a distinctive scrubby landscape known as macquis. Olive trees are common in the coastal plains. In the arid desert areas, there is little natural vegetation although the date palm is extensively cultivated in oases.

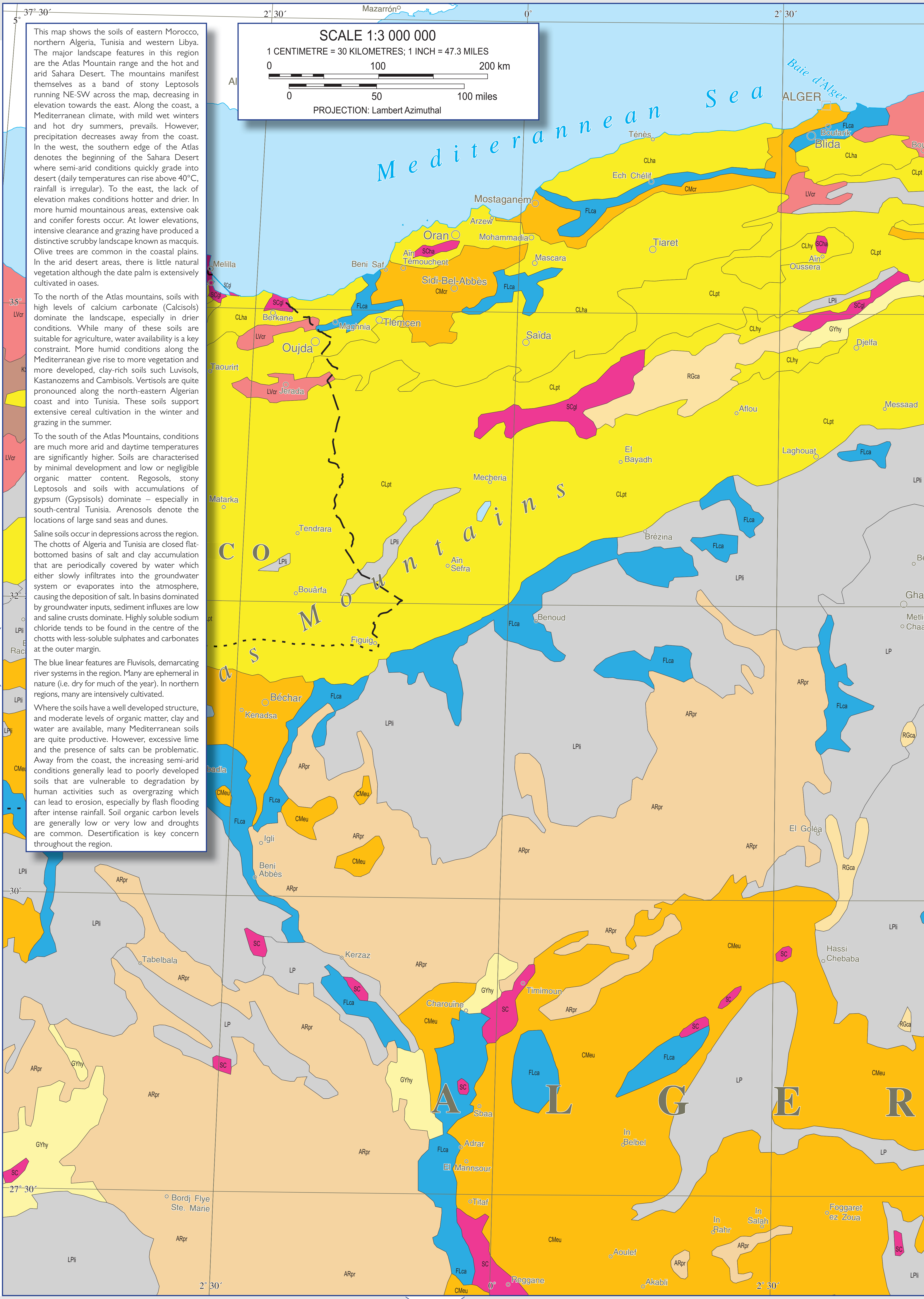
To the north of the Atlas mountains, soils with high levels of calcium carbonate (Calcisols) dominate the landscape, especially in drier conditions. While many of these soils are suitable for agriculture, water availability is a key constraint. More humid conditions along the Mediterranean give rise to more vegetation and more developed, clay-rich soils such Luvisols, Kastanozems and Cambisols. Vertisols are quite pronounced along the north-eastern Algerian coast and into Tunisia. These soils support extensive cereal cultivation in the winter and grazing in the summer.

To the south of the Atlas Mountains, conditions are much more arid and daytime temperatures are significantly higher. Soils are characterised by minimal development and low or negligible organic matter content. Regosols, stony Leptosols and soils with accumulations of gypsum (Gypsisols) dominate – especially in south-central Tunisia. Arenosols denote the locations of large sand seas and dunes.

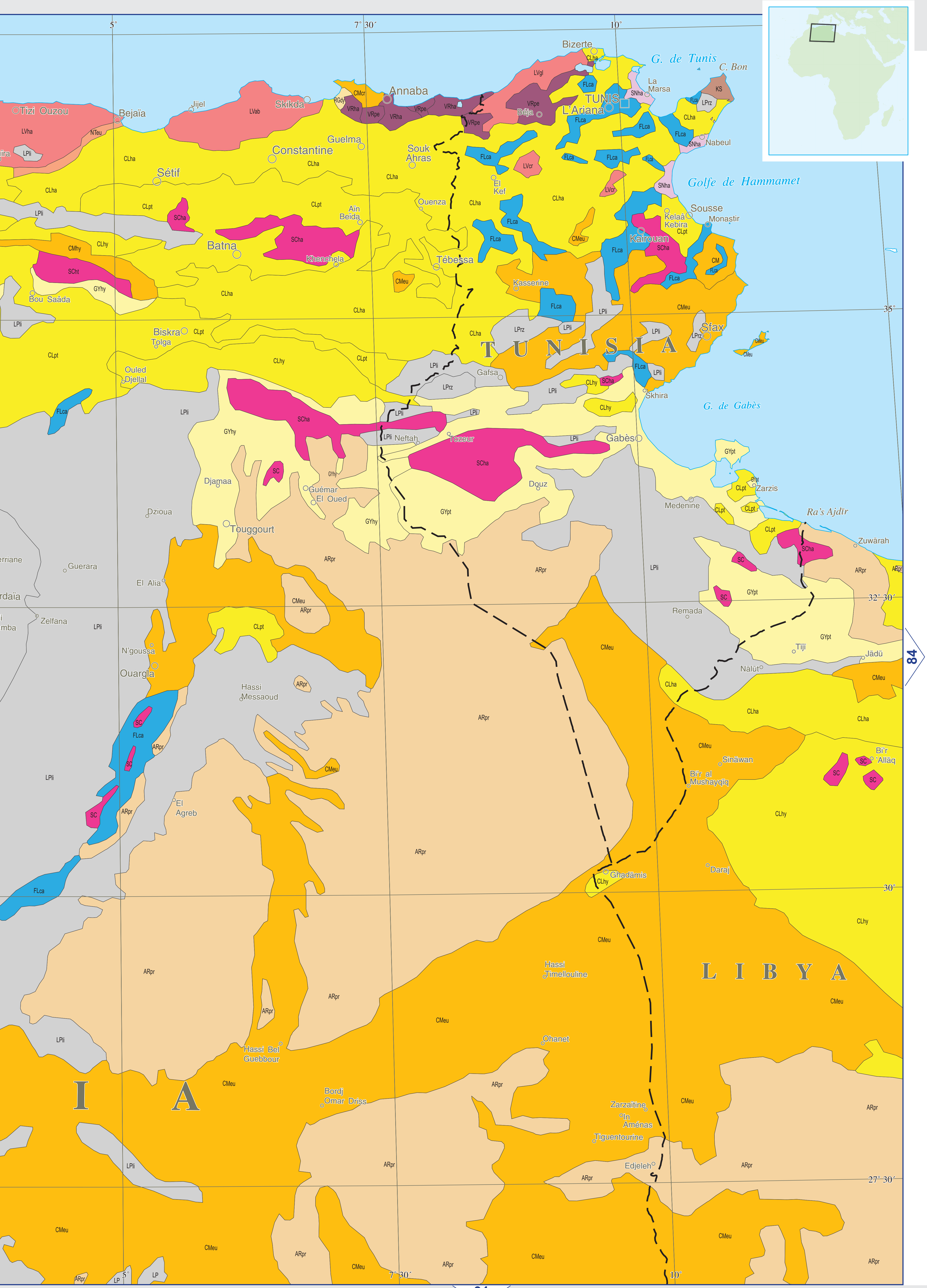
Saline soils occur in depressions across the region. The chotts of Algeria and Tunisia are closed flat-bottomed basins of salt and clay accumulation that are periodically covered by water which either slowly infiltrates into the groundwater system or evaporates into the atmosphere, causing the deposition of salt. In basins dominated by groundwater inputs, sediment influxes are low and saline crusts dominate. Highly soluble sodium chloride tends to be found in the centre of the chotts with less-soluble sulphates and carbonates at the outer margin.

The blue linear features are Fluvisols, demarcating river systems in the region. Many are ephemeral in nature (i.e. dry for much of the year). In northern regions, many are intensively cultivated.

Where the soils have a well developed structure, and moderate levels of organic matter, clay and water are available, many Mediterranean soils are quite productive. However, excessive lime and the presence of salts can be problematic. Away from the coast, the increasing semi-arid conditions generally lead to poorly developed soils that are vulnerable to degradation by human activities such as overgrazing which can lead to erosion, especially by flash flooding after intense rainfall. Soil organic carbon levels are generally low or very low and droughts are common. Desertification is key concern throughout the region.



81
90



5°
7° 30´
10°
35°
32° 30´
30°
27° 30´
G. de Tunis
C. Bon
Bizerte
La Marsa
TUNIS
L'Ariana
Béja
Annaba
Skikda
Jijel
Bejaïa
Tizi Ouzou
Guelma
Constantine
Sétif
Souk Ahras
El Kef
Nabeul
Golfe de Hammamet
Sousse
Monastir
Kelaâ Kebira
Kairouan
Ouenza
Aïn Beida
Batna
Khenchela
Tébessa
Kasserine
Bou Saâda
Biskra
Tolga
Ouled Djellal
Sfax
TUNISIA
Gafsa
Skhira
G. de Gabès
Gabès
Nefta
Tozeur
Douz
Djamaa
Guémar
El Oued
Touggourt
Dzioua
Zarzis
Medenine
Ra's Ajdīr
Zuwārah
Guerara
El Alia
Zelfana
Remada
N'goussa
Ouargla
Tiji
Jādū
Nālūt
Hassi Messaoud
Sināwan
Bi'r 'Allāq
Bi'r al Mushayqīq
El Agreb
Daraj
Ghadāmis
Hassi Timellouline
LIBYA
Ohanet
Hassi Bel Guebbour
IA
Bordj Omar Driss
Zarzaitine
In Aménas
Tiguentourine
Edjeleh
84

91

This map shows the soils of eastern Tunisia, Libya and western Egypt. This map is dominated by the hot and arid Sahara Desert. The absence of the Atlas Mountains means that desert conditions extend much closer to the coastal regions than in the countries to the west. While a Mediterranean climate with mild wet winters and hot dry summers extends along the coast, precipitation decreases and temperatures rapidly increase inland. A narrow band of semi-arid grasslands extends inland from the Mediterranean coast. However, desert conditions border the sea along the Gulf of Sidra in Libya. In the south of the map daily temperatures can rise above 40°C while annual rainfall is low and irregular. Droughts, often lasting several years, are common. The world's highest shaded temperature was recorded in the Libyan Desert. When precipitation levels are higher, the coastal plains and semi-arid regions are covered with herbaceous vegetation and annual grasses. In the arid desert areas, there is little natural vegetation although the date palm is extensively cultivated in oases.

Soils with high levels of calcium carbonate (Calcisols) dominate the landscape, replaced by soils with accumulations of gypsum (Gypsisols) in drier conditions. Arenosols denote the locations of large sand seas and dunes, especially in south-western Libya and on the border with Egypt. Saline soils occur as salt flats or sabkhas along the Libyan coast. These are formed by the ponding and evaporation of water behind coastal dunes. In western Egypt, they occur in closed depressions in the landscape.

The blue linear features are Fluvisols, demarcating river systems in the region. Many are ephemeral in nature (i.e. dry for much of the year).

Soil organic carbon levels are generally low or very low everywhere. Excessive lime and the presence of salts can be problematic in the cultivation of soils in this region. Salinisation due to over-irrigation is damaging some previously fertile soils. Dust and sandstorms are common and wind erosion is a major driver of desertification.

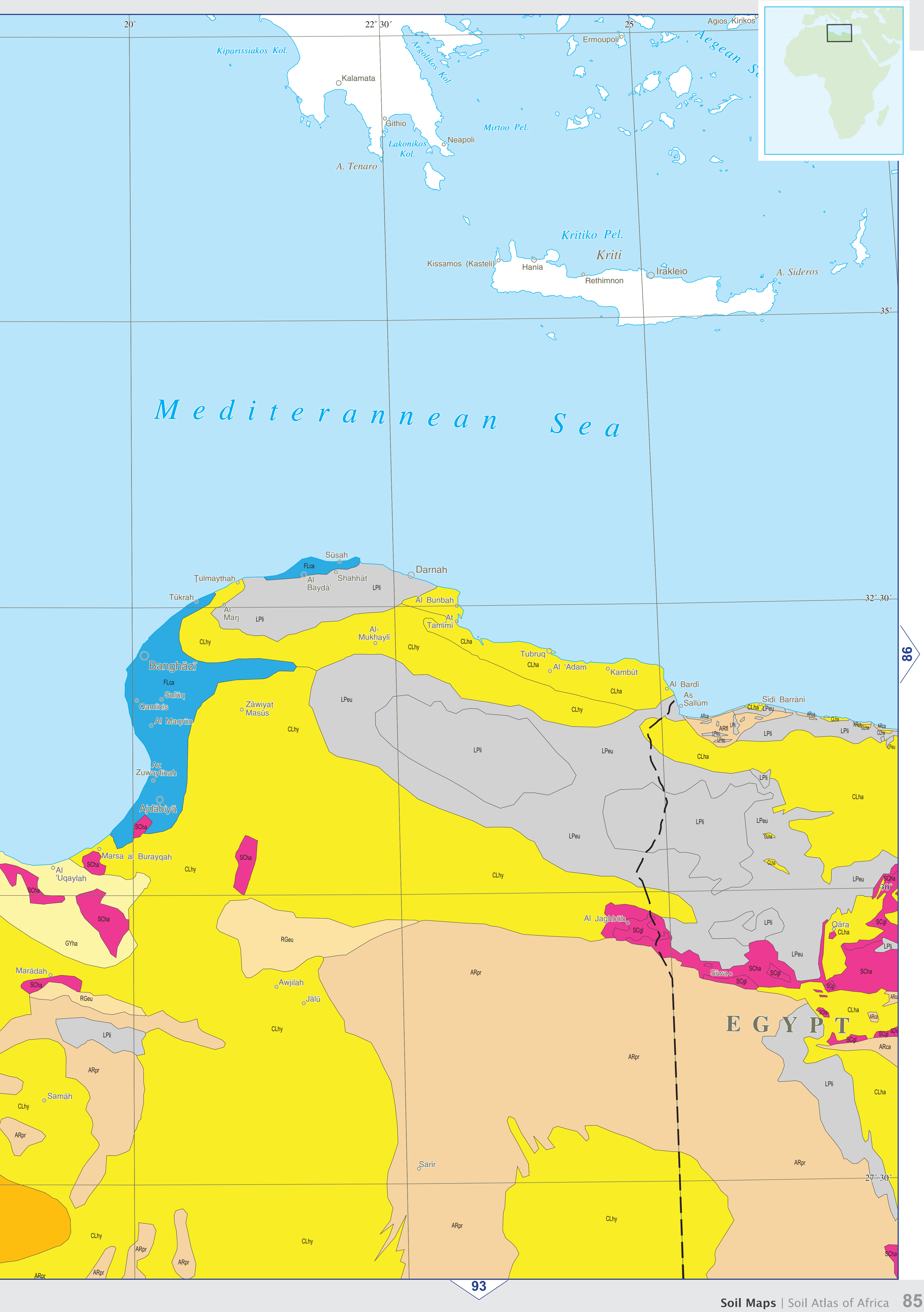
SCALE 1:3 000 000

1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES

0 100 200 km

0 50 100 miles

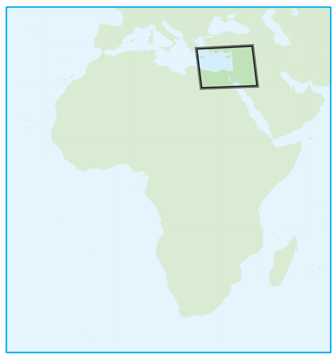
PROJECTION: Lambert Azimuthal



Mediterannean Sea
Aegean Sea
Kiparissiakos Kol.
Argolikos Kol.
Mirtoo Pel.
Lakonikos Kol.
A. Tenaro
Kritiko Pel.
Kriti
A. Sideros
Kalamata
Githio
Neapoli
Ermoupoli
Agios Kirikos
Kissamos (Kasteli)
Hania
Rethimnon
Irakleio
Sūsah
Darnah
Ţulmaythah
Shahhāt
Al Baydā'
Tūkrah
Al Marj
Al Bunbah
At Tamimi
Al-Mukhaylī
Tubruq
Al 'Adam
Kambūt
Al Bardī
As Sallūm
Sīdī Barrānī
Banghāzī
Sulūq
Qaminis
Al Maqrūn
Zāwiyat Masūs
Az Zuwaytīnah
Ajdābiyā
Marsa al Burayqah
Al 'Uqaylah
Al Jaghbūb
Sīwa
Qāra
Marādah
Awjilah
Jālū
Samāh
Sarīr
EGYPT
20°
22° 30´
25°
35°
32° 30´
30°
27° 30´
FLca
LPli
CLhy
CLha
LPeu
SCha
SCgl
GYha
RGeu
ARpr
ARca
ARfl
86
93


Aegean Sea
Mediterranean Sea
Mirtoo Pel.
Kritiko Pel.
Kriti
A. Sideros
CYPRU
LIBYA
E G Y P T
Agios Kirikos
Ermoupoli
Bodrum
Kalimnos
Muğla
Gencek
Antalya
Alanya
Rodos
Hania
Rethimnon
Irakleio
Kambūt
Al Bardī
As Sallūm
Sīdī Barrānī
Marsā Matrūḥ
Fūka
El Daba
Al Alamein
ALEXANDRIA
Rashīd
Baltīm
Dumyāṭ
Port (Būr
Kafe al Sheik
Kafe al Dauwār
Damanhūr
Al Mansūrah
Al Mahalla al Kubra
Ṭanṭā
Shibīn al Kōm
Az Zaqāzīq
Benhā
CAIRO
AL GIZA
Suez
Helwān
Al Is
Ras Zafarana
Al Jaghbūb
Siwa
Qāra
Al Fayyūm
Sinnūris
Beni Suef
Al Fashn
Maghāgha
Beni Mazār
Samālūt
Al Minya
Mallawī
Dalga
Dairūt
El Qūsiya
Manfalūt
Abnūb
Al Badārī
Asyūt
Abū Tīg
Tahtā
Al Bawīṭī
Qaṣr al Farāfrah
37° 30´
35°
32° 30´
30°
27° 30´
25°
27° 30´
30°
32°
CLha
CLhy
LPeu
LPli
ARpr
ARca
SCgl
SCha
FLca
CMca
RGeu
RGca
GYha
ARha
VRha

85
94



This striking image from the MODIS sensor shows almost the same extent as this plate from space. The vegetated areas of the Nile delta and floodplain in green stand out starkly from the bare, unvegetated brown and yellow land. The triangular-shaped area on the west bank of the Nile just south of Cairo is the Al-Fayoum Oasis – a depression in the desert watered by a channel from the Nile. The oasis drains into a large saltwater lake (Birket Qarun). (NASA)

A close-up of the Nile Delta during a dust storm. Note how the delta is almost obscured by blown sand. Wind erosion is an important component of desertification. The white objects on the right of the image are clouds. (NASA)

SCALE 1:3 000 000

1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES

0 100 200 km

0 50 100 miles

PROJECTION: Lambert Azimuthal

This map shows the soils of northern Egypt. As in the previous plate, this map is dominated by the hot and arid Sahara, with desert conditions extending almost to the Mediterranean coast. The area is generally characterised by low annual precipitation and a considerable seasonal and daily temperature range. Alexandria on the coast has a Mediterranean climate with mild wet winters and hot dry summers. It receives around 175 mm of rainfall annually while Cairo, only a little further inland, only receives 25 mm. Levels decrease even further to the south. While the Sinai Peninsula receives somewhat more precipitation, the Red Sea coastal plain and the Western Desert are almost without precipitation.

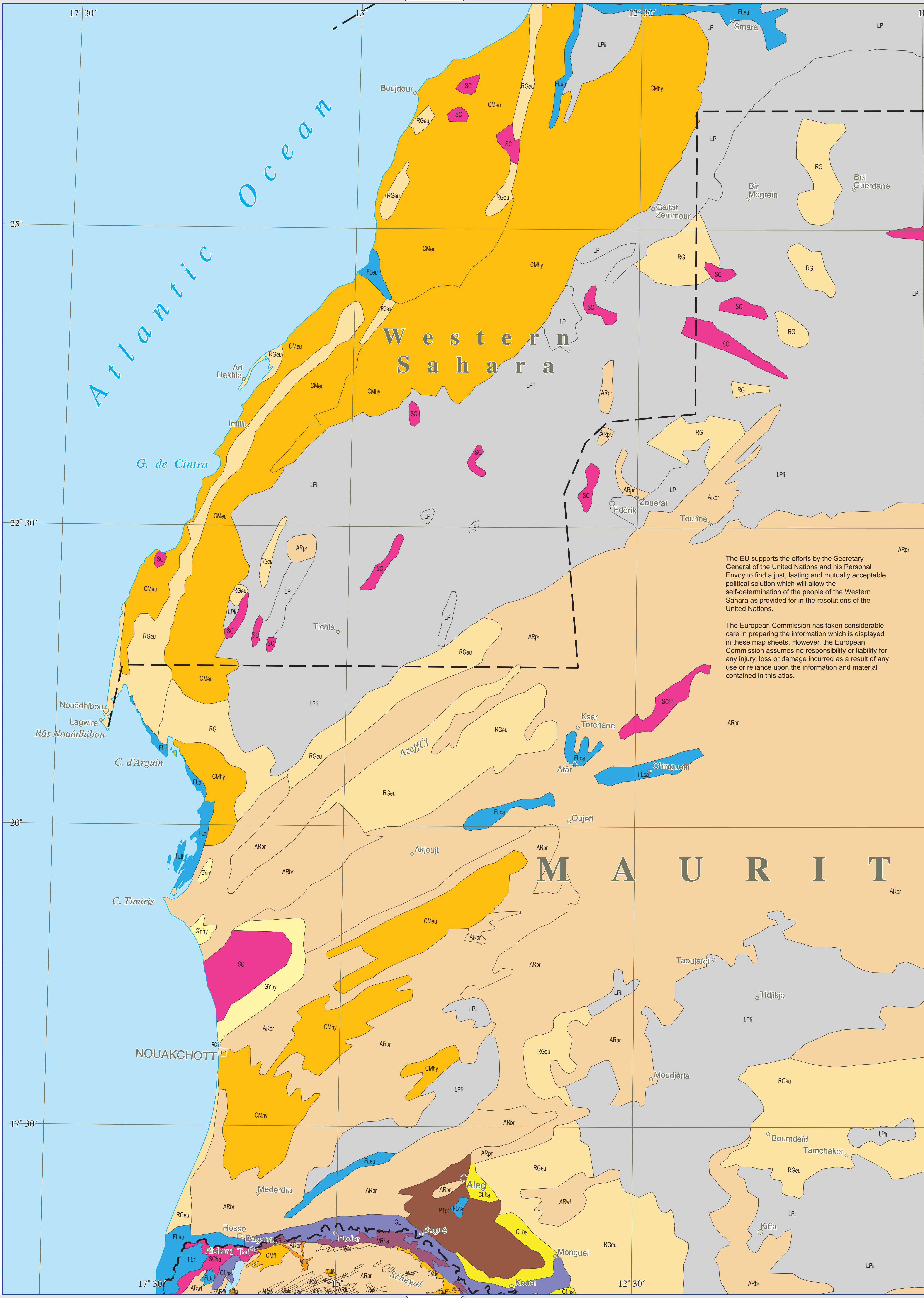
The major geographic element on this map is the River Nile and its delta – the longest river in the world. North of Cairo the Nile forms a distinctive delta (denoted on the map as Fluvisols). This is a level triangular-shaped lowland composed of silt brought mainly from the Ethiopian Plateau and comprises some of the most fertile soils in Africa. The Nile splits Egypt in two: towards Libya lies the vast Western Desert while to the west are the narrower, rocky Eastern and Sinai Deserts.

As evidenced by the satellite photograph above, vegetation outside of the Nile's floodplain and delta is sparse or non-existent. Where water exists, shrubs, thorny perennials and grasses can be found. The Nile supports many varieties of water plants and grasses while the date palm is found throughout the delta, in the Nile valley and in the oases. The Western Desert is almost totally devoid of plant life.

The soils of the map reflect the dry and hot conditions. Weakly developed, medium-textured soils with large gypsum concentrations at shallow depths (Gypsisols) dominate the landscape, interspersed by thin, rocky calcareous soils (Leptosols) and sandy soils (Arenosols), the latter are prevalent in the Western Desert and the Sinai. Saline soils occur as salt flats or sabkhas along the Delta coast. These are formed by the flooding and evaporation of seawater. In the Western Desert, fine-textured saline and sodic soils affected by impeded drainage occur in the Qattara Depression – at 133 m below sea level, the second lowest point in Africa.

While the soils along the Nile are highly productive, urbanisation, salinisation, pollution from pesticides and industrial waste and sand encroachment, together with wind and water erosion, are putting increasing pressure on a scare and limited resource in this region.

80


Atlantic Ocean
Western Sahara
MAURIT
G. de Cintra
C. d'Arguin
C. Timiris
Râs Nouâdhibou
Boujdour
Ad Dakhla
Imlili
Smara
Bir Mogrein
Bel Guerdane
Galtat Zemmour
Fdérik
Zouérat
Tourine
Tichla
Nouâdhibou
Lagwira
Ksar Torchane
Atâr
Chinguetti
Azeffâl
Oujeft
Akjoujt
Taoujafet
Tidjikja
Moudjéria
NOUAKCHOTT
Boumdeïd
Tamchaket
Mederdra
Aleg
Rosso
Dagana
Richard Toll
Podor
Bogué
Monguel
Kiffa
Kaédi
Sénégal
17° 30´
15°
12° 30´
25°
22° 30´
20°
17° 30´
The EU supports the efforts by the Secretary General of the United Nations and his Personal Envoy to find a just, lasting and mutually acceptable political solution which will allow the self-determination of the people of the Western Sahara as provided for in the resolutions of the United Nations.
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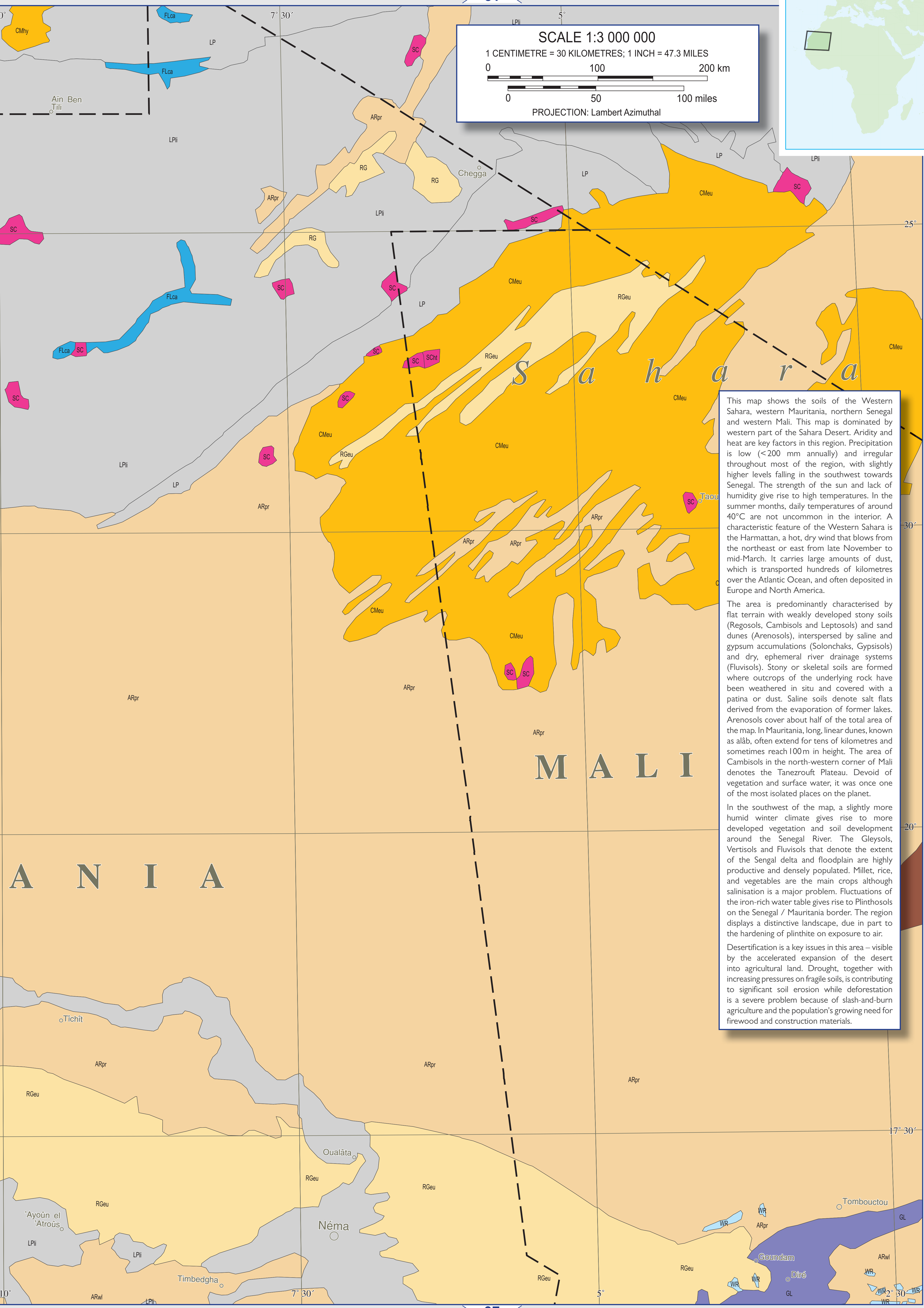
96



This map shows the soils of the Western Sahara, western Mauritania, northern Senegal and western Mali. This map is dominated by western part of the Sahara Desert. Aridity and heat are key factors in this region. Precipitation is low (<200 mm annually) and irregular throughout most of the region, with slightly higher levels falling in the southwest towards Senegal. The strength of the sun and lack of humidity give rise to high temperatures. In the summer months, daily temperatures of around 40°C are not uncommon in the interior. A characteristic feature of the Western Sahara is the Harmattan, a hot, dry wind that blows from the northeast or east from late November to mid-March. It carries large amounts of dust, which is transported hundreds of kilometres over the Atlantic Ocean, and often deposited in Europe and North America.

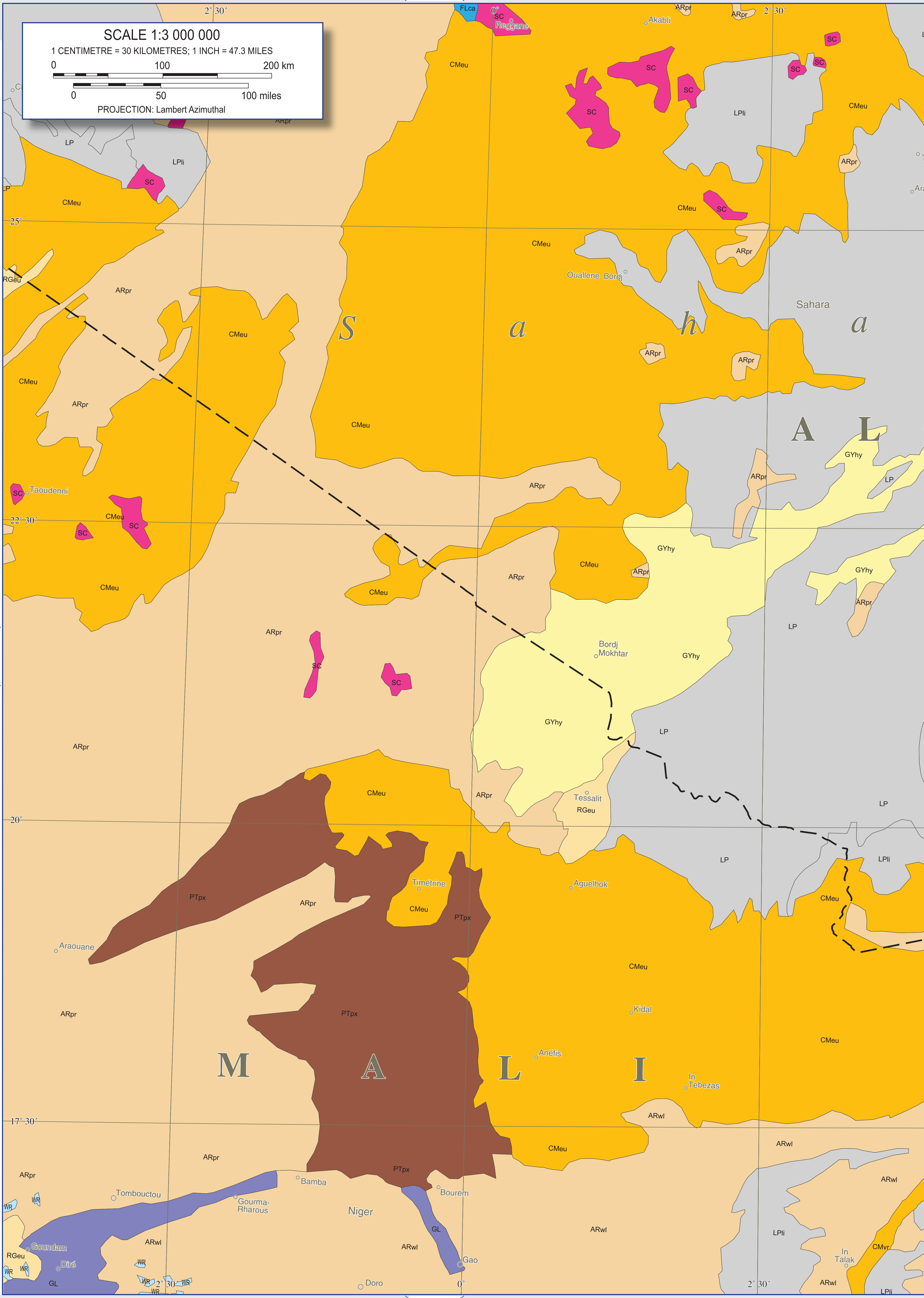
The area is predominantly characterised by flat terrain with weakly developed stony soils (Regosols, Cambisols and Leptosols) and sand dunes (Arenosols), interspersed by saline and gypsum accumulations (Solonchaks, Gypsisols) and dry, ephemeral river drainage systems (Fluvisols). Stony or skeletal soils are formed where outcrops of the underlying rock have been weathered in situ and covered with a patina or dust. Saline soils denote salt flats derived from the evaporation of former lakes. Arenosols cover about half of the total area of the map. In Mauritania, long, linear dunes, known as alâb, often extend for tens of kilometres and sometimes reach 100 m in height. The area of Cambisols in the north-western corner of Mali denotes the Tanezrouft Plateau. Devoid of vegetation and surface water, it was once one of the most isolated places on the planet.

In the southwest of the map, a slightly more humid winter climate gives rise to more developed vegetation and soil development around the Senegal River. The Gleysols, Vertisols and Fluvisols that denote the extent of the Sengal delta and floodplain are highly productive and densely populated. Millet, rice, and vegetables are the main crops although salinisation is a major problem. Fluctuations of the iron-rich water table gives rise to Plinthosols on the Senegal / Mauritania border. The region displays a distinctive landscape, due in part to the hardening of plinthite on exposure to air.

Desertification is a key issues in this area – visible by the accelerated expansion of the desert into agricultural land. Drought, together with increasing pressures on fragile soils, is contributing to significant soil erosion while deforestation is a severe problem because of slash-and-burn agriculture and the population's growing need for firewood and construction materials.

90
97

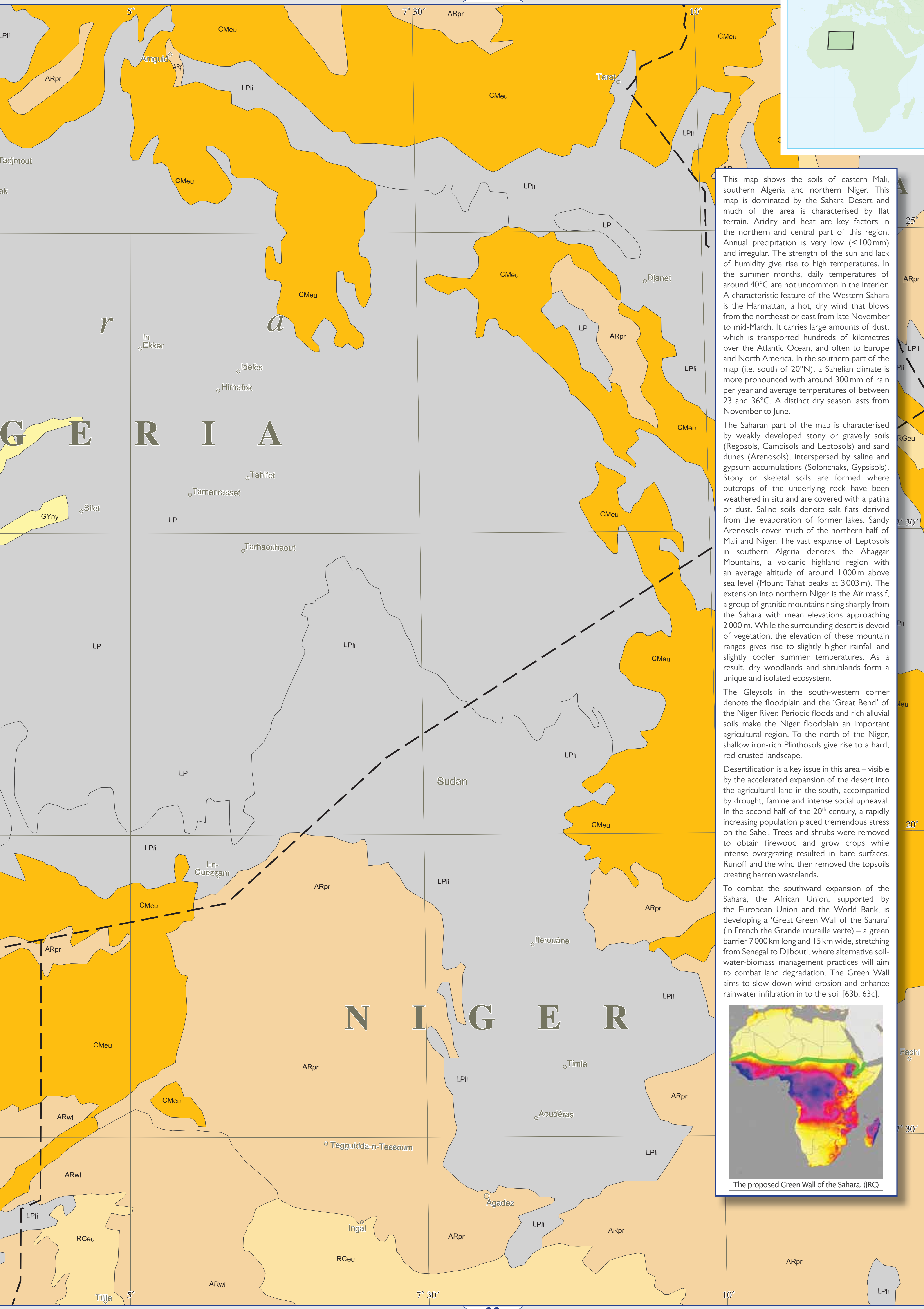
82


SCALE 1:3 000 000
1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES
0
100
200 km
0
50
100 miles
PROJECTION: Lambert Azimuthal
2° 30´
0°
Reggane
Akabli
FLca
SC
CMeu
LPli
LP
ARpr
25°
RGeu
Ouallene Bordj
Sahara
S
a
h
a
A
L
GYhy
Taoudenni
22° 30´
Bordj Mokhtar
Tessalit
20°
Timétrine
Aguelhok
PTpx
Araouane
Kidal
Anéfis
M
A
L
I
In Tebezas
17° 30´
ARwl
Bamba
Bourem
Tombouctou
Gourma-Rharous
Niger
Goundam
Diré
GL
WR
Gao
Doro
In Talak
CMvr

89

98

83



This map shows the soils of eastern Mali, southern Algeria and northern Niger. This map is dominated by the Sahara Desert and much of the area is characterised by flat terrain. Aridity and heat are key factors in the northern and central part of this region. Annual precipitation is very low (<100mm) and irregular. The strength of the sun and lack of humidity give rise to high temperatures. In the summer months, daily temperatures of around 40°C are not uncommon in the interior. A characteristic feature of the Western Sahara is the Harmattan, a hot, dry wind that blows from the northeast or east from late November to mid-March. It carries large amounts of dust, which is transported hundreds of kilometres over the Atlantic Ocean, and often to Europe and North America. In the southern part of the map (i.e. south of 20°N), a Sahelian climate is more pronounced with around 300mm of rain per year and average temperatures of between 23 and 36°C. A distinct dry season lasts from November to June.

The Saharan part of the map is characterised by weakly developed stony or gravelly soils (Regosols, Cambisols and Leptosols) and sand dunes (Arenosols), interspersed by saline and gypsum accumulations (Solonchaks, Gypsisols). Stony or skeletal soils are formed where outcrops of the underlying rock have been weathered in situ and are covered with a patina or dust. Saline soils denote salt flats derived from the evaporation of former lakes. Sandy Arenosols cover much of the northern half of Mali and Niger. The vast expanse of Leptosols in southern Algeria denotes the Ahaggar Mountains, a volcanic highland region with an average altitude of around 1000m above sea level (Mount Tahat peaks at 3003m). The extension into northern Niger is the Aïr massif, a group of granitic mountains rising sharply from the Sahara with mean elevations approaching 2000 m. While the surrounding desert is devoid of vegetation, the elevation of these mountain ranges gives rise to slightly higher rainfall and slightly cooler summer temperatures. As a result, dry woodlands and shrublands form a unique and isolated ecosystem.

The Gleysols in the south-western corner denote the floodplain and the 'Great Bend' of the Niger River. Periodic floods and rich alluvial soils make the Niger floodplain an important agricultural region. To the north of the Niger, shallow iron-rich Plinthosols give rise to a hard, red-crusted landscape.

Desertification is a key issue in this area – visible by the accelerated expansion of the desert into the agricultural land in the south, accompanied by drought, famine and intense social upheaval. In the second half of the 20th century, a rapidly increasing population placed tremendous stress on the Sahel. Trees and shrubs were removed to obtain firewood and grow crops while intense overgrazing resulted in bare surfaces. Runoff and the wind then removed the topsoils creating barren wastelands.

To combat the southward expansion of the Sahara, the African Union, supported by the European Union and the World Bank, is developing a 'Great Green Wall of the Sahara' (in French the Grande muraille verte) – a green barrier 7000km long and 15km wide, stretching from Senegal to Djibouti, where alternative soil-water-biomass management practices will aim to combat land degradation. The Green Wall aims to slow down wind erosion and enhance rainwater infiltration in to the soil [63b, 63c].

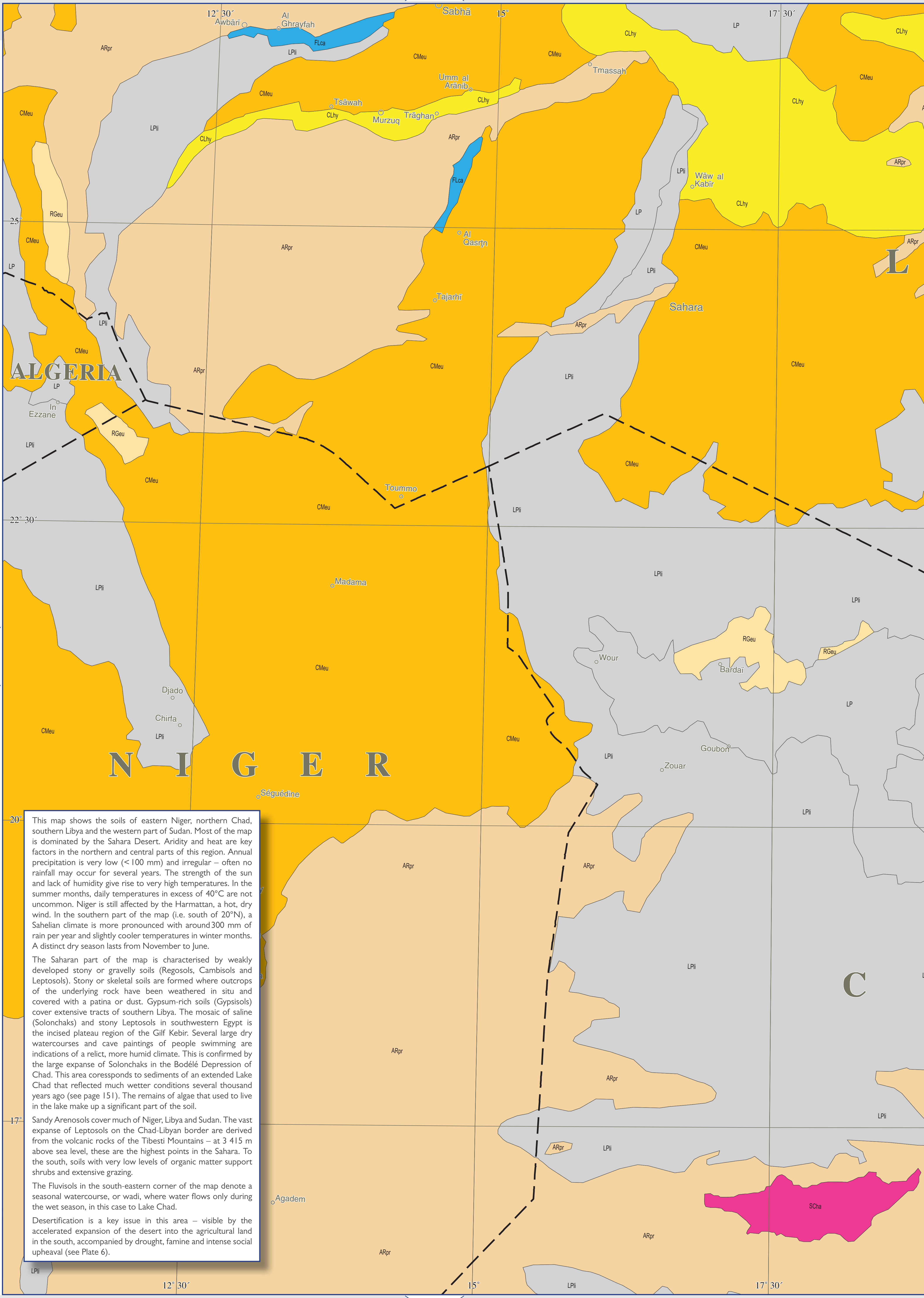
The proposed Green Wall of the Sahara. (JRC)

92

99

84

91



This map shows the soils of eastern Niger, northern Chad, southern Libya and the western part of Sudan. Most of the map is dominated by the Sahara Desert. Aridity and heat are key factors in the northern and central parts of this region. Annual precipitation is very low (<100 mm) and irregular – often no rainfall may occur for several years. The strength of the sun and lack of humidity give rise to very high temperatures. In the summer months, daily temperatures in excess of 40°C are not uncommon. Niger is still affected by the Harmattan, a hot, dry wind. In the southern part of the map (i.e. south of 20°N), a Sahelian climate is more pronounced with around 300 mm of rain per year and slightly cooler temperatures in winter months. A distinct dry season lasts from November to June.

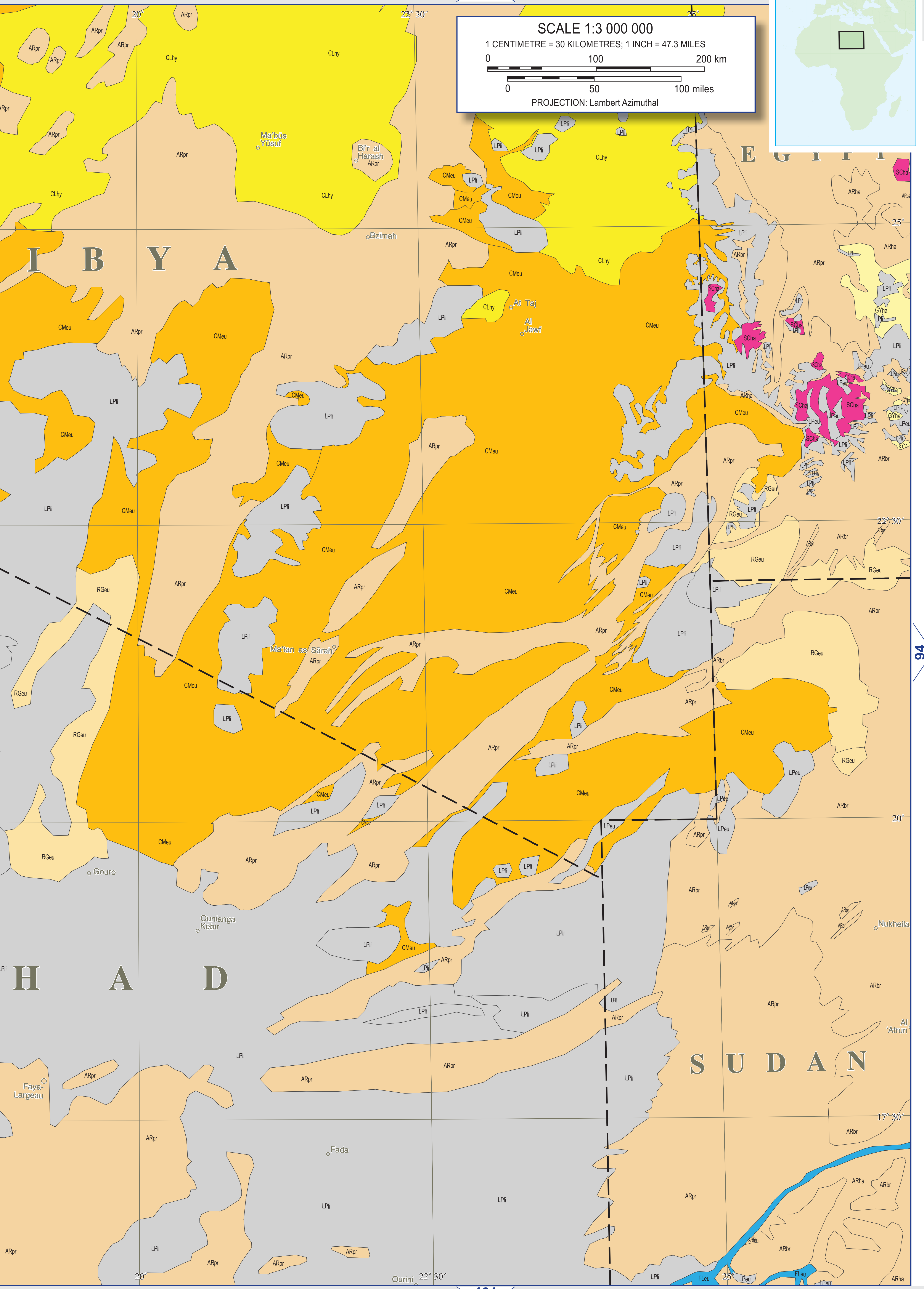
The Saharan part of the map is characterised by weakly developed stony or gravelly soils (Regosols, Cambisols and Leptosols). Stony or skeletal soils are formed where outcrops of the underlying rock have been weathered in situ and covered with a patina or dust. Gypsum-rich soils (Gypsisols) cover extensive tracts of southern Libya. The mosaic of saline (Solonchaks) and stony Leptosols in southwestern Egypt is the incised plateau region of the Gilf Kebir. Several large dry watercourses and cave paintings of people swimming are indications of a relict, more humid climate. This is confirmed by the large expanse of Solonchaks in the Bodélé Depression of Chad. This area coressponds to sediments of an extended Lake Chad that reflected much wetter conditions several thousand years ago (see page 151). The remains of algae that used to live in the lake make up a significant part of the soil.

Sandy Arenosols cover much of Niger, Libya and Sudan. The vast expanse of Leptosols on the Chad-Libyan border are derived from the volcanic rocks of the Tibesti Mountains – at 3 415 m above sea level, these are the highest points in the Sahara. To the south, soils with very low levels of organic matter support shrubs and extensive grazing.

The Fluvisols in the south-eastern corner of the map denote a seasonal watercourse, or wadi, where water flows only during the wet season, in this case to Lake Chad.

Desertification is a key issue in this area – visible by the accelerated expansion of the desert into the agricultural land in the south, accompanied by drought, famine and intense social upheaval (see Plate 6).

100

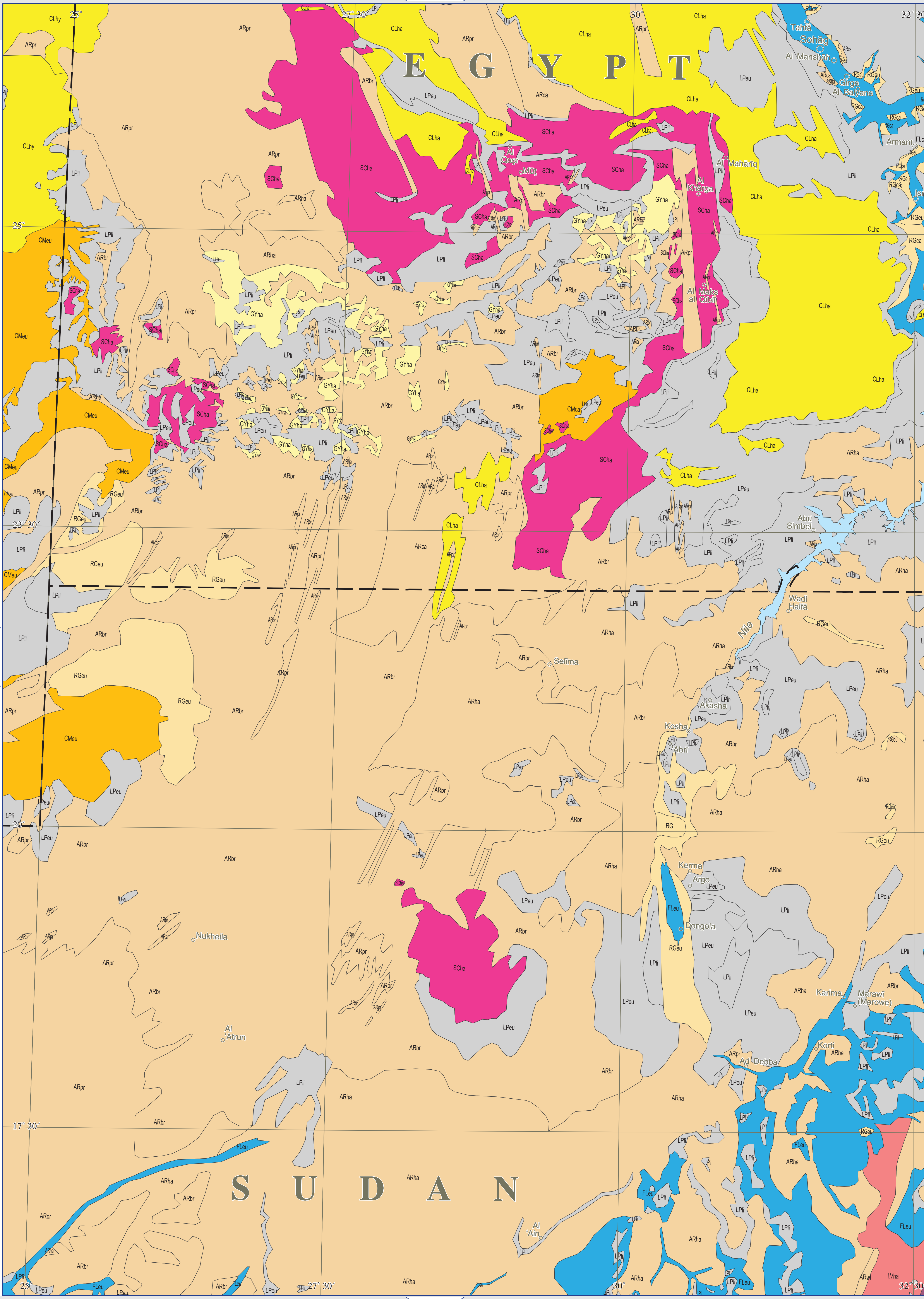

SCALE 1:3 000 000
1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES
0
100
200 km
0
50
100 miles
PROJECTION: Lambert Azimuthal
LIBYA
EGYPT
CHAD
SUDAN
Ma'būs Yūsuf
Bi'r al Harash
Bzīmah
At Taj
Al Jawf
Ma'tan as Sārah
Gouro
Ounianga Kebir
Faya-Largeau
Fada
Ourini
Nukheila
Al 'Atrun
20°
22° 30´
25°
17° 30´
CLhy
ARpr
CMeu
LPli
RGeu
ARbr
ARha
SCha
LPeu
GYha
FLeu

94

101

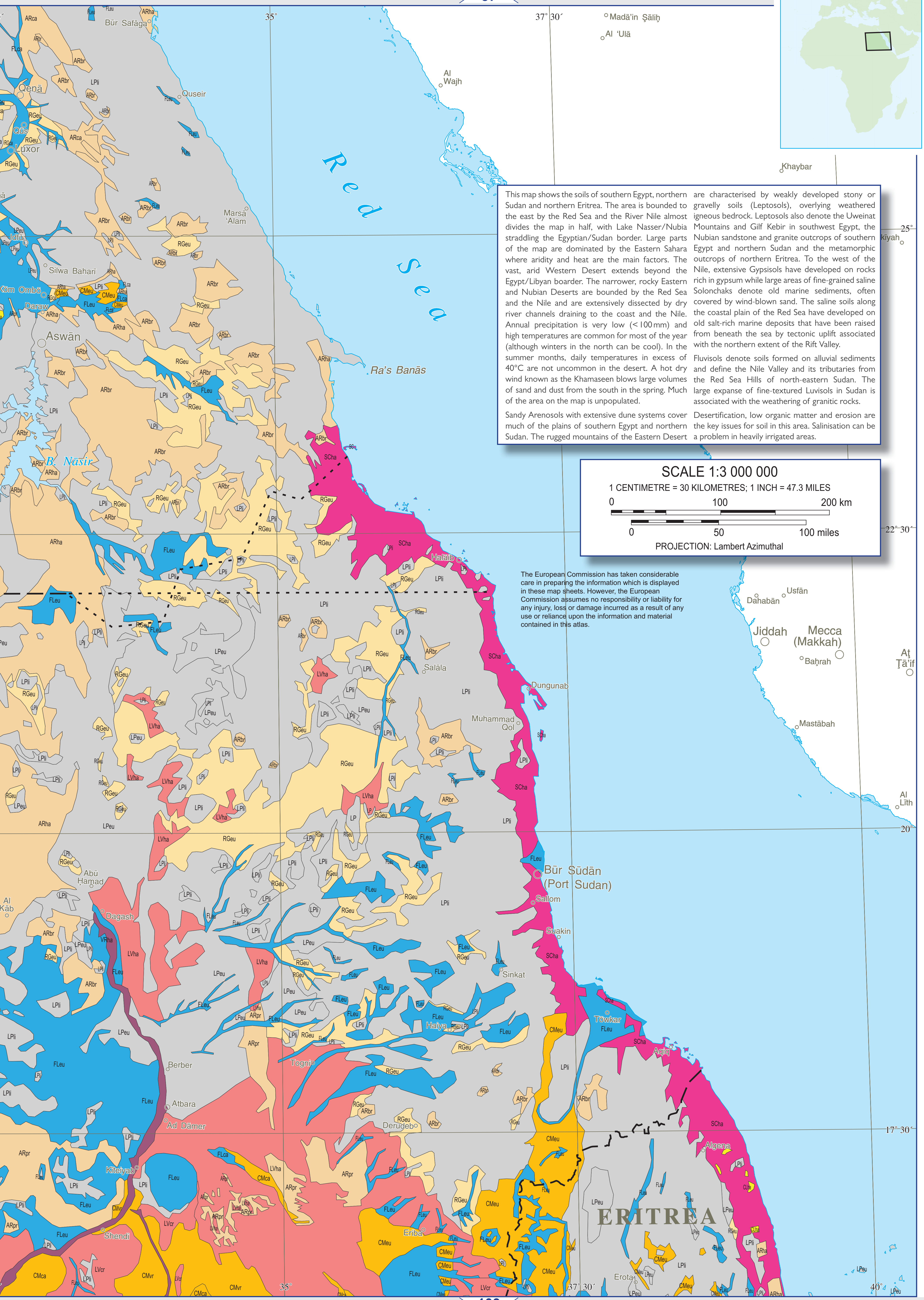
86

93


EGYPT
SUDAN
Tahta
Sohâg
Al Manshâh
Girga
Al Balyana
Armant
Al Qasr
Mût
Al Mahâriq
Al Khârga
Al Maks al Qiblî
Abû Simbel
Wadi Halfa
Nile
Selima
Akasha
Kosha
Abri
Kerma
Argo
Dongola
Karima
Marawi (Merowe)
Korti
Ad Debba
Nukheila
Al 'Atrun
Al 'Ain
25°
27° 30´
30°
32° 30´
22° 30´
20°
17° 30´

102

87



This map shows the soils of southern Egypt, northern Sudan and northern Eritrea. The area is bounded to the east by the Red Sea and the River Nile almost divides the map in half, with Lake Nasser/Nubia straddling the Egypt/Sudan border. Large parts of the map are dominated by the Eastern Sahara where aridity and heat are the main factors. The vast, arid Western Desert extends beyond the Egypt/Libyan boarder. The narrower, rocky Eastern and Nubian Deserts are bounded by the Red Sea and the Nile and are extensively dissected by dry river channels draining to the coast and the Nile. Annual precipitation is very low (<100 mm) and high temperatures are common for most of the year (although winters in the north can be cool). In the summer months, daily temperatures in excess of 40°C are not uncommon in the desert. A hot dry wind known as the Khamaseen blows large volumes of sand and dust from the south in the spring. Much of the area on the map is unpopulated.

Sandy Arenosols with extensive dune systems cover much of the plains of southern Egypt and northern Sudan. The rugged mountains of the Eastern Desert are characterised by weakly developed stony or gravelly soils (Leptosols), overlying weathered igneous bedrock. Leptosols also denote the Uweinat Mountains and Gilf Kebir in southwest Egypt, the Nubian sandstone and granite outcrops of southern Egypt and northern Sudan and the metamorphic outcrops of northern Eritrea. To the west of the Nile, extensive Gypsisols have developed on rocks rich in gypsum while large areas of fine-grained saline Solonchaks denote old marine sediments, often covered by wind-blown sand. The saline soils along the coastal plain of the Red Sea have developed on old salt-rich marine deposits that have been raised from beneath the sea by tectonic uplift associated with the northern extent of the Rift Valley.

Fluvisols denote soils formed on alluvial sediments and define the Nile Valley and its tributaries from the Red Sea Hills of north-eastern Sudan. The large expanse of fine-textured Luvisols in Sudan is associated with the weathering of granitic rocks.

Desertification, low organic matter and erosion are the key issues for soil in this area. Salinisation can be a problem in heavily irrigated areas.

SCALE 1:3 000 000

1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES

0 100 200 km

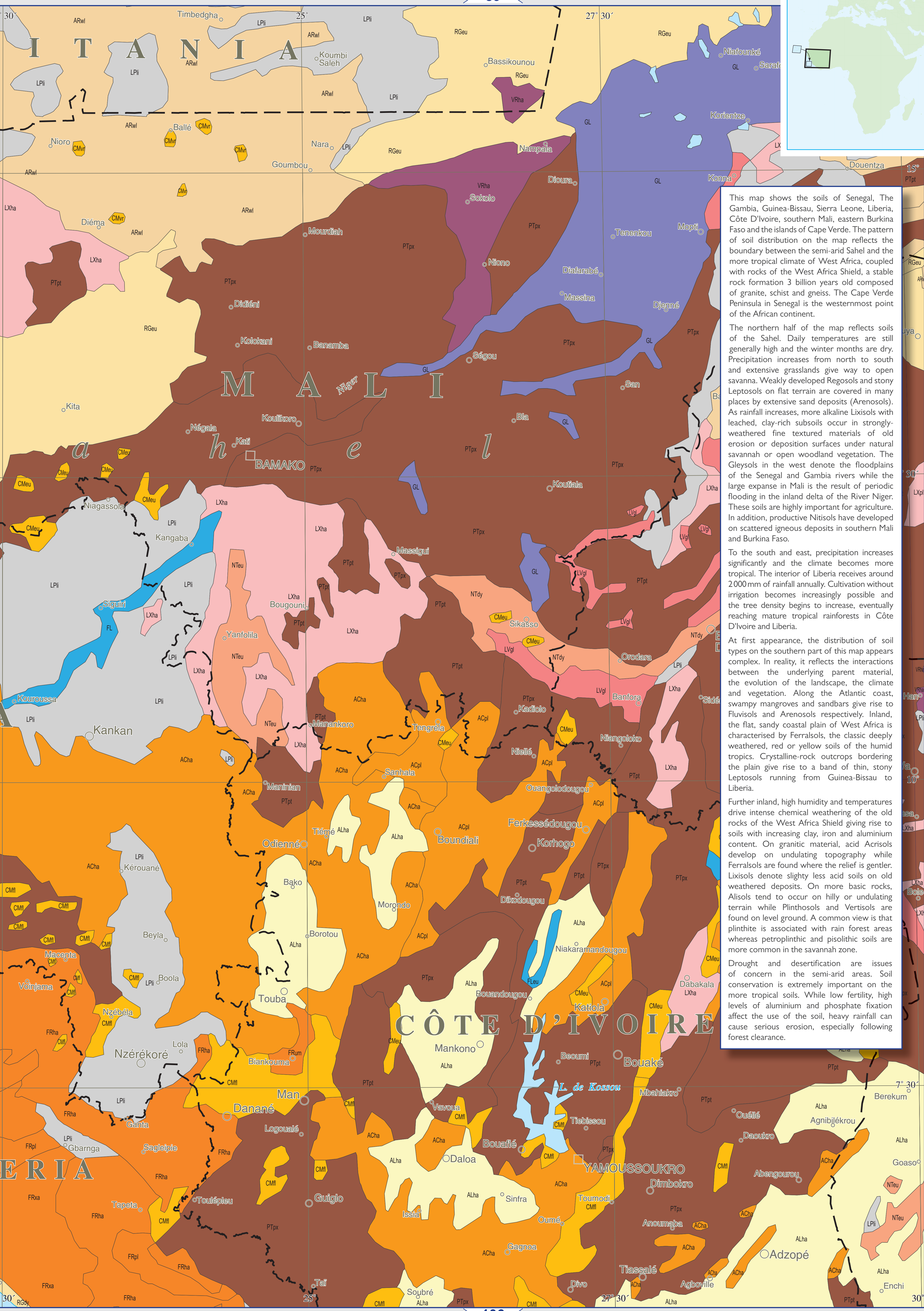
0 50 100 miles

PROJECTION: Lambert Azimuthal

103


SENEGAL
THE GAMBIA
GUINEA-BISSAU
GUINEA
SIERRA LEONE
MAURITANIA
LIBERIA
CAPE VERDE
Atlantic Ocean
Atlantic Ocean
DAKAR
BANJUL
BISSAU
CONAKRY
FREETOWN
MONROVIA
PRAIA
St.-Louis
Louga
Kébémer
Mekhé
Tivaouane
Thiès
Rufisque
Mbour
Joal-Fadiout
Bambey
Diourbel
Mbaké
Fatick
Foundiougne
Kaolack
Kaffrine
Guinguinéo
Sokone
Nioro
Dara
Linguère
Koumpentoum
Koungheul
Koussanar
Tambacounda
Maka
Bala
Goudiri
Kidira
Bakel
Matam
Kaédi
Maghama
Diamounguel
Mbout
Sélibabi
Kayes
Ambidédi
Yélimané
Dioka
Sandaré
Bafoulabé
Kéniéba
Satadougou
Kerewan
Brikama
Georgetown
Basse Santa Su
Vélingara
Dialakoto
Kolda
Sédhiou
Bignona
Ziguinchor
Diouloulou
Farim
São Domingos
Canchungo
Mansôa
Bafatá
Nova Lamego
Bolama
Koundara
Foulamory
Koumbia
Gaoual
Labé
Mali
Pita
Télimélé
Dalaba
Mamou
Kindia
Fria
Boké
Victoria
Boffa
Forécariah
Dinguiraye
Bissikrima
Dabola
Siguiri
Faranah
Tiro
Kissidougou
Kambia
Batkanu
Port Loko
Lunsar
Pepel
Makeni
Magburaka
Marampa
Yonibana
Yele
Waterloo
Moyamba
Shenge
Bo
Kenema
Pendembu
Kailahun
Koindu
Gueckédou
Zimmi
Bopolu
Bomi Hills
Kakata
Harbel
Marshall
Buchanan
C. Vert
C. Roxo
Sénégal
SCALE 1:3 000 000
1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES
0 100 200 km
0 50 100 miles
PROJECTION: Lambert Azimuthal
Ribeira Grande
Mindelo
São Vicente
Ribeira Brava
São Nicolau
Pedra Lume
Sal-Rei
Tarrafal
São Tiago

89



This map shows the soils of Senegal, The Gambia, Guinea-Bissau, Sierra Leone, Liberia, Côte D'Ivoire, southern Mali, eastern Burkina Faso and the islands of Cape Verde. The pattern of soil distribution on the map reflects the boundary between the semi-arid Sahel and the more tropical climate of West Africa, coupled with rocks of the West Africa Shield, a stable rock formation 3 billion years old composed of granite, schist and gneiss. The Cape Verde Peninsula in Senegal is the westernmost point of the African continent.

The northern half of the map reflects soils of the Sahel. Daily temperatures are still generally high and the winter months are dry. Precipitation increases from north to south and extensive grasslands give way to open savanna. Weakly developed Regosols and stony Leptosols on flat terrain are covered in many places by extensive sand deposits (Arenosols). As rainfall increases, more alkaline Lixisols with leached, clay-rich subsoils occur in strongly-weathered fine textured materials of old erosion or deposition surfaces under natural savannah or open woodland vegetation. The Gleysols in the west denote the floodplains of the Senegal and Gambia rivers while the large expanse in Mali is the result of periodic flooding in the inland delta of the River Niger. These soils are highly important for agriculture. In addition, productive Nitisols have developed on scattered igneous deposits in southern Mali and Burkina Faso.

To the south and east, precipitation increases significantly and the climate becomes more tropical. The interior of Liberia receives around 2000 mm of rainfall annually. Cultivation without irrigation becomes increasingly possible and the tree density begins to increase, eventually reaching mature tropical rainforests in Côte D'Ivoire and Liberia.

At first appearance, the distribution of soil types on the southern part of this map appears complex. In reality, it reflects the interactions between the underlying parent material, the evolution of the landscape, the climate and vegetation. Along the Atlantic coast, swampy mangroves and sandbars give rise to Fluvisols and Arenosols respectively. Inland, the flat, sandy coastal plain of West Africa is characterised by Ferralsols, the classic deeply weathered, red or yellow soils of the humid tropics. Crystalline-rock outcrops bordering the plain give rise to a band of thin, stony Leptosols running from Guinea-Bissau to Liberia.

Further inland, high humidity and temperatures drive intense chemical weathering of the old rocks of the West Africa Shield giving rise to soils with increasing clay, iron and aluminium content. On granitic material, acid Acrisols develop on undulating topography while Ferralsols are found where the relief is gentler. Lixisols denote slighty less acid soils on old weathered deposits. On more basic rocks, Alisols tend to occur on hilly or undulating terrain while Plinthosols and Vertisols are found on level ground. A common view is that plinthite is associated with rain forest areas whereas petroplinthic and pisolithic soils are more common in the savannah zone.

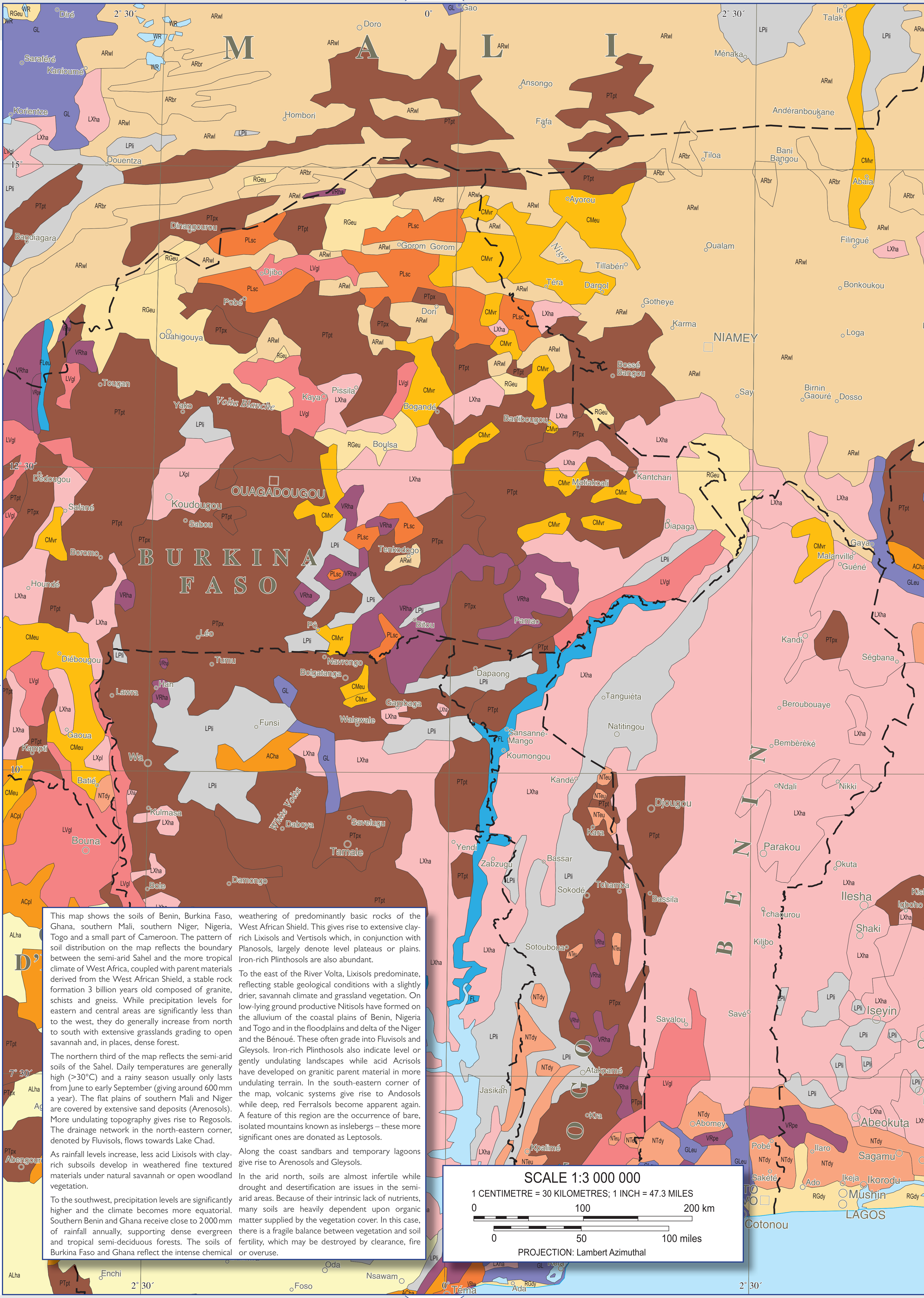
Drought and desertification are issues of concern in the semi-arid areas. Soil conservation is extremely important on the more tropical soils. While low fertility, high levels of aluminium and phosphate fixation affect the use of the soil, heavy rainfall can cause serious erosion, especially following forest clearance.

98

106

90

97



This map shows the soils of Benin, Burkina Faso, Ghana, southern Mali, southern Niger, Nigeria, Togo and a small part of Cameroon. The pattern of soil distribution on the map reflects the boundary between the semi-arid Sahel and the more tropical climate of West Africa, coupled with parent materials derived from the West African Shield, a stable rock formation 3 billion years old composed of granite, schists and gneiss. While precipitation levels for eastern and central areas are significantly less than to the west, they do generally increase from north to south with extensive grasslands grading to open savannah and, in places, dense forest.

The northern third of the map reflects the semi-arid soils of the Sahel. Daily temperatures are generally high (>30°C) and a rainy season usually only lasts from June to early September (giving around 600 mm a year). The flat plains of southern Mali and Niger are covered by extensive sand deposits (Arenosols). More undulating topography gives rise to Regosols. The drainage network in the north-eastern corner, denoted by Fluvisols, flows towards Lake Chad.

As rainfall levels increase, less acid Lixisols with clay-rich subsoils develop in weathered fine textured materials under natural savannah or open woodland vegetation.

To the southwest, precipitation levels are significantly higher and the climate becomes more equatorial. Southern Benin and Ghana receive close to 2 000 mm of rainfall annually, supporting dense evergreen and tropical semi-deciduous forests. The soils of Burkina Faso and Ghana reflect the intense chemical weathering of predominantly basic rocks of the West African Shield. This gives rise to extensive clay-rich Lixisols and Vertisols which, in conjunction with Planosols, largely denote level plateaus or plains. Iron-rich Plinthosols are also abundant.

To the east of the River Volta, Lixisols predominate, reflecting stable geological conditions with a slightly drier, savannah climate and grassland vegetation. On low-lying ground productive Nitisols have formed on the alluvium of the coastal plains of Benin, Nigeria and Togo and in the floodplains and delta of the Niger and the Bénoué. These often grade into Fluvisols and Gleysols. Iron-rich Plinthosols also indicate level or gently undulating landscapes while acid Acrisols have developed on granitic parent material in more undulating terrain. In the south-eastern corner of the map, volcanic systems give rise to Andosols while deep, red Ferralsols become apparent again. A feature of this region are the occurrence of bare, isolated mountains known as inslebergs – these more significant ones are donated as Leptosols.

Along the coast sandbars and temporary lagoons give rise to Arenosols and Gleysols.

In the arid north, soils are almost infertile while drought and desertification are issues in the semi-arid areas. Because of their intrinsic lack of nutrients, many soils are heavily dependent upon organic matter supplied by the vegetation cover. In this case, there is a fragile balance between vegetation and soil fertility, which may be destroyed by clearance, fire or overuse.

SCALE 1:3 000 000

1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES

0 100 200 km

0 50 100 miles

PROJECTION: Lambert Azimuthal

107

91

NIGER
NIGERIA
CAMEROON
Sahel
Tillia
Abalak
Tahoua
Tanout
Illéla
Bouza
Dakoro
Dabnou
Madaoua
Malbaza
Birnin-Konni
Dogondoutchi
Tessaoua
Zinder
Miria
Guidimouni
Gouré
Goudoumaria
Boultoum
Gazamni
Chéri
Maradi
Gazaoua
Ouatcha
Dungas
Magaria
Daura
Katsina
Jibiya
Wurno
Sokoto
Isa
Lema
Argungu
Birnin Kebbi
Jega
Gummi
Moriki
Talata Mafara
Kaura Namoda
Zurmi
Ingawa
Gumel
Hadejia
Nguru
Gashua
Katagum
Danbatta
Kunya
Kano
Ringim
Gaya
Kura
Azare
Potiskum
Gusau
Anka
Dan Gulbi
Funtua
Malumfashi
Birnin Kudu
Fokku
Zuru
Wasagu
Zaria
Soba
Ningi
Nafada
Duku
Bara
Gombe
Kumo
Yelwa
Bin Yauri
Kusheriki
Kaduna
Bauchi
Jos
Bukuru
Auna
Tegina
Zungeru
Kachia
Wawa
Kaiama
Minna
Mokwa
Bida
Lapai
ABUJA
Pankshin
Shendam
Jebba
Lafiagi
Pategi
Keffi
Akwanga
Igbetti
Baro
Nasarawa
Lafia
Jalingo
Ilorin
Offa
Ogbomosho
Ilobu
Ila
Oshogbo
Ede
Iwo
Ile Ife
Ikire
IBADAN
Ilesa
Effon-Alaiye
Ado Ekiti
Ikerre
Ilawe-Ekiti
Akure
Ondo
Owo
Ikare
Oka
Kabba
Lokoja
Okene
Auchi
Idah
Uromi
Tunga
Ibi
Wukari
Makurdi
Beli
Takum
Gboko
Ankpa
Enugu Ezike
Nsukka
Eha Amufu
Enugu
Obudu
Ogoja
Nkambe
Mayo Daga
Abakaliki
Awka
Onitsha
Asaba
Afikpo
Ikom
Mamfé
Bamenda
Kumbo
Foumban
Ijebu Ode
Okitipupa
Benin City
Sapele
Niger
Bénue

100

108

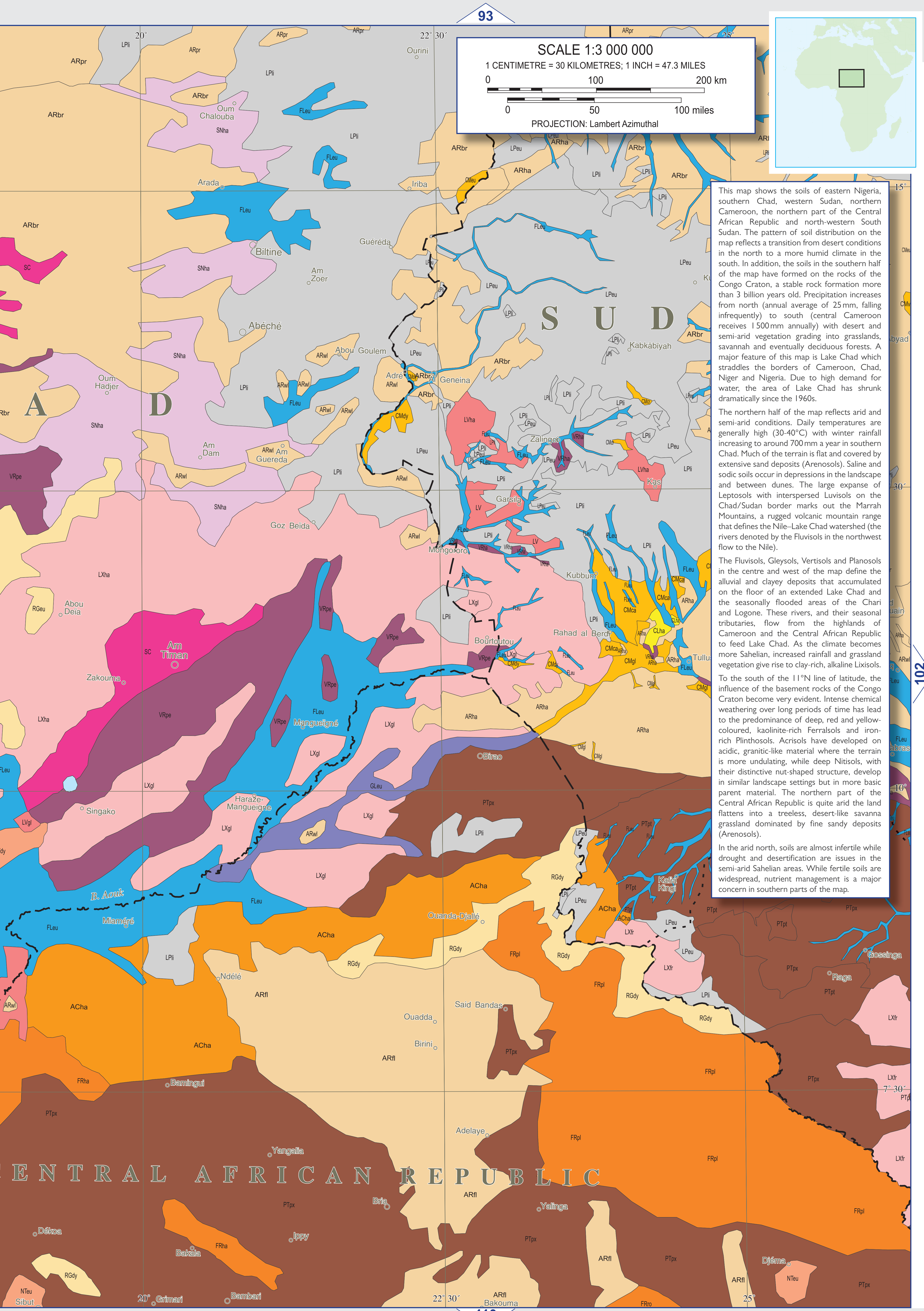
92

99


NIGER
NIGERIA
CH
CAMEROON
L. Chad
N'DJAMENA
Maiduguri
Maroua
Garoua
Ngaoundéré
Moundou
Doba
Sarh
Laï
Bongor
Mongo
Ati
Bossangoa
Bouar
Bozoum
Bocaranga
Meiganga
Termit
Bélabirim
Nguigmi
Rig Rig
Nokou
Mao
Mondo
Ngouri
Moussoro
Salal
Nédéley
Koro Toro
Djédaa
Massakori
Massaguet
Goudoumaria
Kélekam
Chéri
Diffa
Maïné Soroa
Baga
Kukawa
Mongonu
Dapchi
Magumeri
Damaturu
Murguba
Bama
Dikwa
Makari
Dourbali
Massénya
Guélengdeng
Bousso
Chari
Mora
Mokolo
Waza
Yagoua
Kaélé
Guider
Bibémi
Pala
Kélo
Beinamar
Goundi
Koumra
Moïssala
Goré
Baïbokoum
Tchollire
Poli
Mbé
Tibati
Banyo
Kimi
Sangbé
Garoua Boulaï
Baboua
Bossemptélé
Bouca
Batangafo
Kouki
Korbol
Miltou
Melfi
Temki
Bokoro
Yao
Djéména
Buni
Dumboa
Biu
Garkida
Gombi
Shani
Mubi
Song
Numan
Jimeta
Yola
Jada
Jalingo
Toungo
Kontcha
Mayo Daga
Gombe
Kumo
Nafada
Jen
Lau
Benue
Niger
12° 30´
15°
17° 30´
10°
7° 30´

109

93



This map shows the soils of eastern Nigeria, southern Chad, western Sudan, northern Cameroon, the northern part of the Central African Republic and north-western South Sudan. The pattern of soil distribution on the map reflects a transition from desert conditions in the north to a more humid climate in the south. In addition, the soils in the southern half of the map have formed on the rocks of the Congo Craton, a stable rock formation more than 3 billion years old. Precipitation increases from north (annual average of 25 mm, falling infrequently) to south (central Cameroon receives 1 500 mm annually) with desert and semi-arid vegetation grading into grasslands, savannah and eventually deciduous forests. A major feature of this map is Lake Chad which straddles the borders of Cameroon, Chad, Niger and Nigeria. Due to high demand for water, the area of Lake Chad has shrunk dramatically since the 1960s.

The northern half of the map reflects arid and semi-arid conditions. Daily temperatures are generally high (30-40°C) with winter rainfall increasing to around 700 mm a year in southern Chad. Much of the terrain is flat and covered by extensive sand deposits (Arenosols). Saline and sodic soils occur in depressions in the landscape and between dunes. The large expanse of Leptosols with interspersed Luvisols on the Chad/Sudan border marks out the Marrah Mountains, a rugged volcanic mountain range that defines the Nile–Lake Chad watershed (the rivers denoted by the Fluvisols in the northwest flow to the Nile).

The Fluvisols, Gleysols, Vertisols and Planosols in the centre and west of the map define the alluvial and clayey deposits that accumulated on the floor of an extended Lake Chad and the seasonally flooded areas of the Chari and Logone. These rivers, and their seasonal tributaries, flow from the highlands of Cameroon and the Central African Republic to feed Lake Chad. As the climate becomes more Sahelian, increased rainfall and grassland vegetation give rise to clay-rich, alkaline Lixisols.

To the south of the 11°N line of latitude, the influence of the basement rocks of the Congo Craton become very evident. Intense chemical weathering over long periods of time has lead to the predominance of deep, red and yellow-coloured, kaolinite-rich Ferralsols and iron-rich Plinthosols. Acrisols have developed on acidic, granitic-like material where the terrain is more undulating, while deep Nitisols, with their distinctive nut-shaped structure, develop in similar landscape settings but in more basic parent material. The northern part of the Central African Republic is quite arid the land flattens into a treeless, desert-like savanna grassland dominated by fine sandy deposits (Arenosols).

In the arid north, soils are almost infertile while drought and desertification are issues in the semi-arid Sahelian areas. While fertile soils are widespread, nutrient management is a major concern in southern parts of the map.

102

110

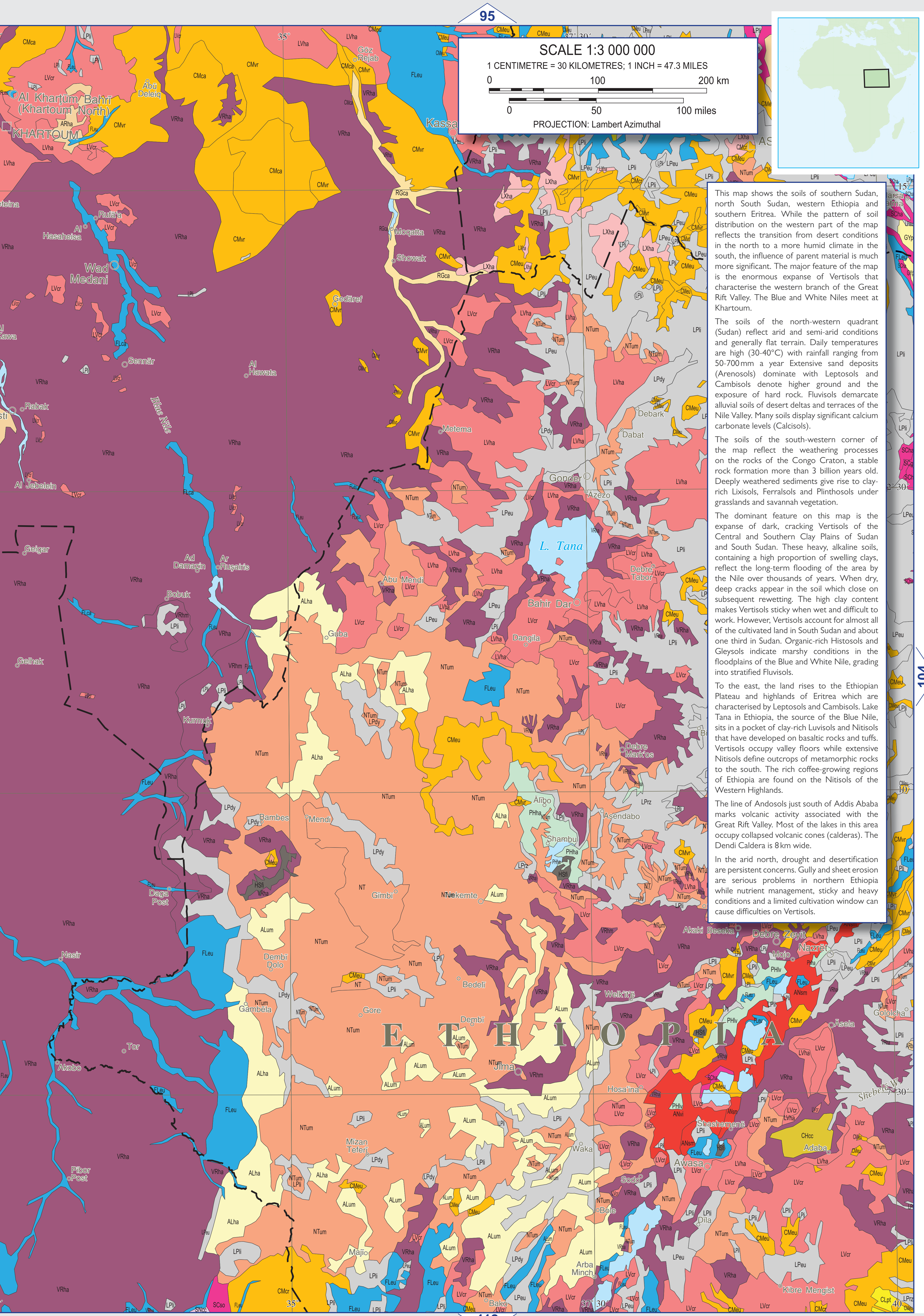
94


SUDAN
SOUTH SUDAN
CENTRAL AFRICAN REPUBLIC
Omdurman
Malha
Mellit
Khureit
Al Fāshir
Abyad
Umm Keddāda
Al Hilla
Ermil
Umm Bel
Hamrat ash Sheikh
Ruweiba
As Safiya
Sodiri
Kagmar
Umm Saiyālah
Bara
Ad Dueim
Iyāl Bakhīt
Wad Banda
Al Obeid
At Taiyāra
Derafīsa
Umm Ruwaba
Tandaltī
Ar Rahad
An Nahūd
Nyala
Taweisha
Ghubeish
Al Odaiya
Abū Zabad
Dilling
Delami
Rashad
Al Lagowa
Abū Gubeiha
Kadugli
Talodi
Ad Duain
Abū Matariq
Abū Gabra
Al Muglad
Buram
Gabras
Sumeih
Abyei
Qurdūd
Kaka
Kodok
Malakal
White Nile
Nyamlell
Aweil
Chak Chak
Gossinga
Raga
Gogrial
Meshra'er Req
Fangak
Abwong
Nyerol
Mogogh
Ayod
Wau
Tonj
Shambe
Kongor
Rumbek
Yirol
Mvolo
Bor
Malek
Tombe
Djéma
25°
27° 30´
30°
32° 30´
15°
12° 30´
10°
7° 30´

101

111

95



This map shows the soils of southern Sudan, north South Sudan, western Ethiopia and southern Eritrea. While the pattern of soil distribution on the western part of the map reflects the transition from desert conditions in the north to a more humid climate in the south, the influence of parent material is much more significant. The major feature of the map is the enormous expanse of Vertisols that characterise the western branch of the Great Rift Valley. The Blue and White Niles meet at Khartoum.

The soils of the north-western quadrant (Sudan) reflect arid and semi-arid conditions and generally flat terrain. Daily temperatures are high (30-40°C) with rainfall ranging from 50-700 mm a year Extensive sand deposits (Arenosols) dominate with Leptosols and Cambisols denote higher ground and the exposure of hard rock. Fluvisols demarcate alluvial soils of desert deltas and terraces of the Nile Valley. Many soils display significant calcium carbonate levels (Calcisols).

The soils of the south-western corner of the map reflect the weathering processes on the rocks of the Congo Craton, a stable rock formation more than 3 billion years old. Deeply weathered sediments give rise to clay-rich Lixisols, Ferralsols and Plinthosols under grasslands and savannah vegetation.

The dominant feature on this map is the expanse of dark, cracking Vertisols of the Central and Southern Clay Plains of Sudan and South Sudan. These heavy, alkaline soils, containing a high proportion of swelling clays, reflect the long-term flooding of the area by the Nile over thousands of years. When dry, deep cracks appear in the soil which close on subsequent rewetting. The high clay content makes Vertisols sticky when wet and difficult to work. However, Vertisols account for almost all of the cultivated land in South Sudan and about one third in Sudan. Organic-rich Histosols and Gleysols indicate marshy conditions in the floodplains of the Blue and White Nile, grading into stratified Fluvisols.

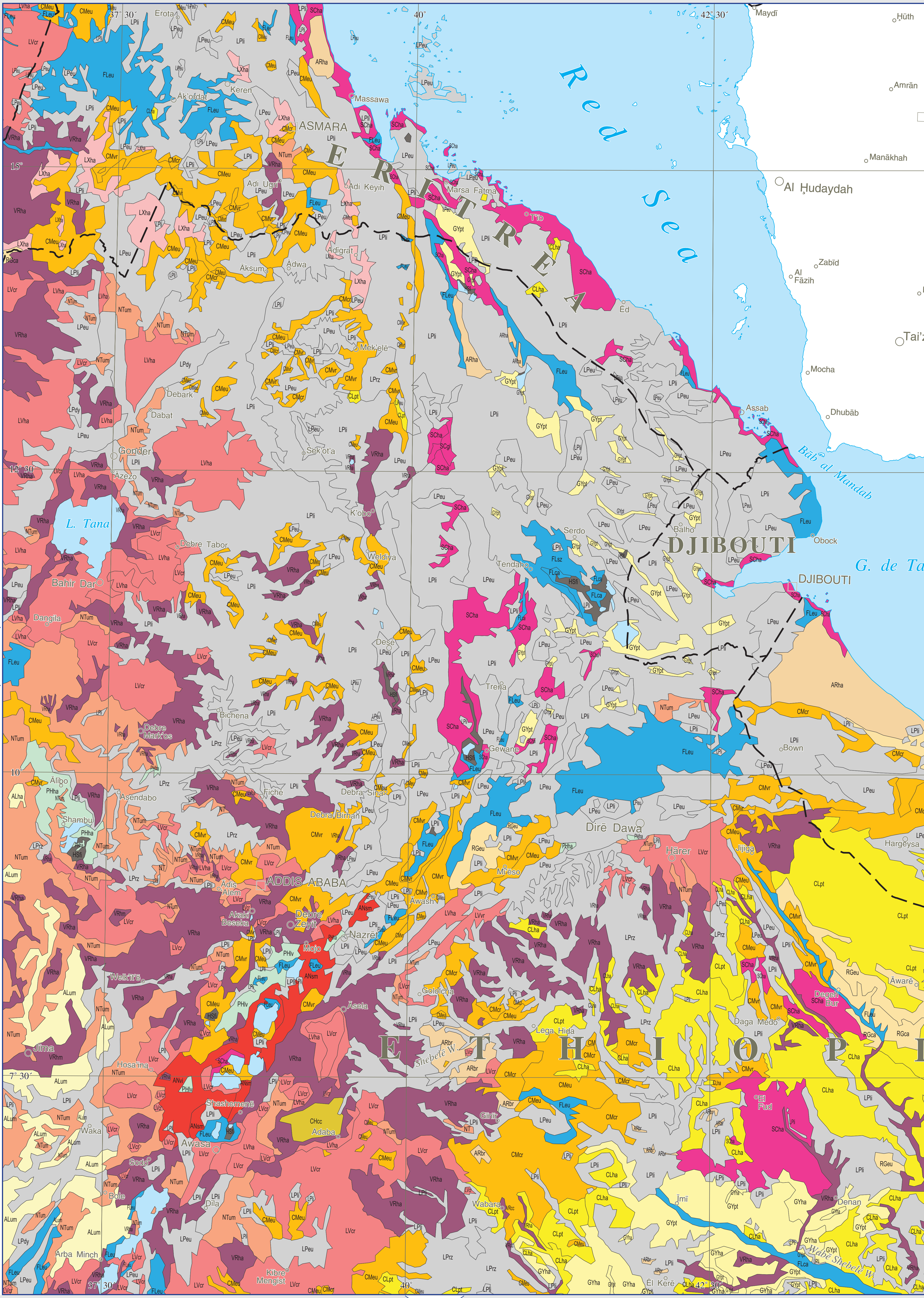
To the east, the land rises to the Ethiopian Plateau and highlands of Eritrea which are characterised by Leptosols and Cambisols. Lake Tana in Ethiopia, the source of the Blue Nile, sits in a pocket of clay-rich Luvisols and Nitisols that have developed on basaltic rocks and tuffs. Vertisols occupy valley floors while extensive Nitisols define outcrops of metamorphic rocks to the south. The rich coffee-growing regions of Ethiopia are found on the Nitisols of the Western Highlands.

The line of Andosols just south of Addis Ababa marks volcanic activity associated with the Great Rift Valley. Most of the lakes in this area occupy collapsed volcanic cones (calderas). The Dendi Caldera is 8 km wide.

In the arid north, drought and desertification are persistent concerns. Gully and sheet erosion are serious problems in northern Ethiopia while nutrient management, sticky and heavy conditions and a limited cultivation window can cause difficulties on Vertisols.

104

112


Red Sea
ERITREA
ETHIOPIA
DJIBOUTI
G. de Ta
Bāb al Mandab
ASMARA
ADDIS ABABA
DJIBOUTI
Massawa
Keren
Ak'ordat
Erota
Adi Ugri
Adi Keyih
Marsa Fatma
Tio
Adigrat
Adwa
Aksum
Ed
Mek'ele
Debark
Dabat
Gonder
Azezo
Sek'ot'a
L. Tana
Debre Tabor
Bahir Dar
Dangila
K'obo
Weldiya
Dese
Bichena
Debre Mark'os
Fiche
Debre Sina
Debra Birhan
Asendabo
Aribo
Shambu
Adis Alem
Akaki Beseka
Debre Zeyit
Nazret
Mojo
Awash
Welkite
Āsela
Gololcha
Jima
Hosa'ina
Shashemenē
Awasa
Adaba
Waka
Sodo
Bole
Dila
Arba Minch
Kibre Mengist
Serdo
Tendaho
Trena
Gewane
Mi'eso
Dirē Dawa
Hārer
Jijiga
Hargeysa
Lega Hida
Ginir
Daga Medo
Degeh Bur
El Fud
Aware
Wabara
Imī
Denan
El Kerē
Shebele W.
Wabē Shebelē W.
Assab
Balho
Obock
Bown
Maydī
Hūth
Amrān
Manākhah
Al Ḩudaydah
Zabīd
Al Fāzih
Tai'z
Mocha
Dhubāb
15°
12° 30′
10°
7° 30′
37° 30′
40°
42° 30′

103

112

This map shows the soils of Djibouti, southern Eritrea, eastern Ethiopia and northern Somalia – an area commonly known as the 'Horn of Africa'. The overall pattern of soil distribution reflects two distinct lithological and climatological regions. To the north and the west, slightly cooler temperatures and significantly more rainfall (up to 2000 mm annually) characterise the volcanic highlands of western Ethiopia while to the south and east, increasing aridity and high temperature give rise to soils dominated by salts, gypsum and calcium carbonate. Parts of Djibouti only receive 130 mm of rain per year, falling on less than 30 days while the summer temperatures on the northern coast of Somalia averages more than 38 °C. At 51°27'52" E, Ras Hafun in Somalia is the most easterly point of the African continent.

The highly weathered material on the mountains of the highlands of Eritrea and the Ethiopian Plateau to the east of Lake Tana are characterised by poorly developed Leptosols and Cambisols. Clayey Luvisols have developed on volcanic rocks but are prone to erosion and display low nutrient retention and crusting.

The line of Andosols just south of Addis Ababa marks the Great Rift Valley which separates the rocky soils of the Djibouti, Eritrea and the Western Highlands in Ethiopia from the Eastern Highlands of Ethiopia and the sediments of Somalia. Many of the lakes in this area occupy collapsed volcanic cones (calderas).

Towards the Red Sea, the floor of the Rift Valley and the Danakil Plain are covered by alluvial sediments (Fluvisols), saline soils (Solonchaks) and gravelly Leptosols. In the western half of the map, pockets of Vertisols occupy valley floors while extensive Nitisols define outcrops of alkaline volcanic and metamorphic rocks. The rich coffee-growing regions of Ethiopia are found predominantly on Nitisols.

To the southeast of the Eastern Highlands of Ethiopia, the soil pattern changes markedly. The soils of south-eastern Ethiopia and northern Somalia have developed under arid and semi-arid conditions. Crystalline basement rocks in northern Somalia give rise to extensive Leptosols and Cambisols. The soils of the Ogaden region of Ethiopia and central Somalia have developed on relatively flat terrain in sediments derived from the weathering of recently deposited sandstones, limestone, marls, clays and evaporites. Calcisols, Gypsisols and Solonchaks denote the specific chemistry of the underlying parent material while the Solonchaks along the coast of Eritrea have evolved in uplifted marine sediments.

The linear patterns of Vertisols and Fluvisols crossing the Ethiopian/Somalian border in the centre of the map denote the fertile alluvial soils on the floodplains of the agriculturally important Jubba and Shabeelle rivers.

In the arid north, drought and desertification are persistent concerns. Gully and sheet erosion are serious problems in northern Ethiopia while nutrient management, sticky and heavy conditions and a limited cultivation window can cause difficulties on Vertisols.

The Horn of Africa is one of the most food-insecure regions in the world with more than 40% of the population deemed undernourished. The FAO estimates that this proportion rises to 70% in Eritrea and Somalia. Drought, conflict, population growth and nutrient-poor soils are all contributing factors.

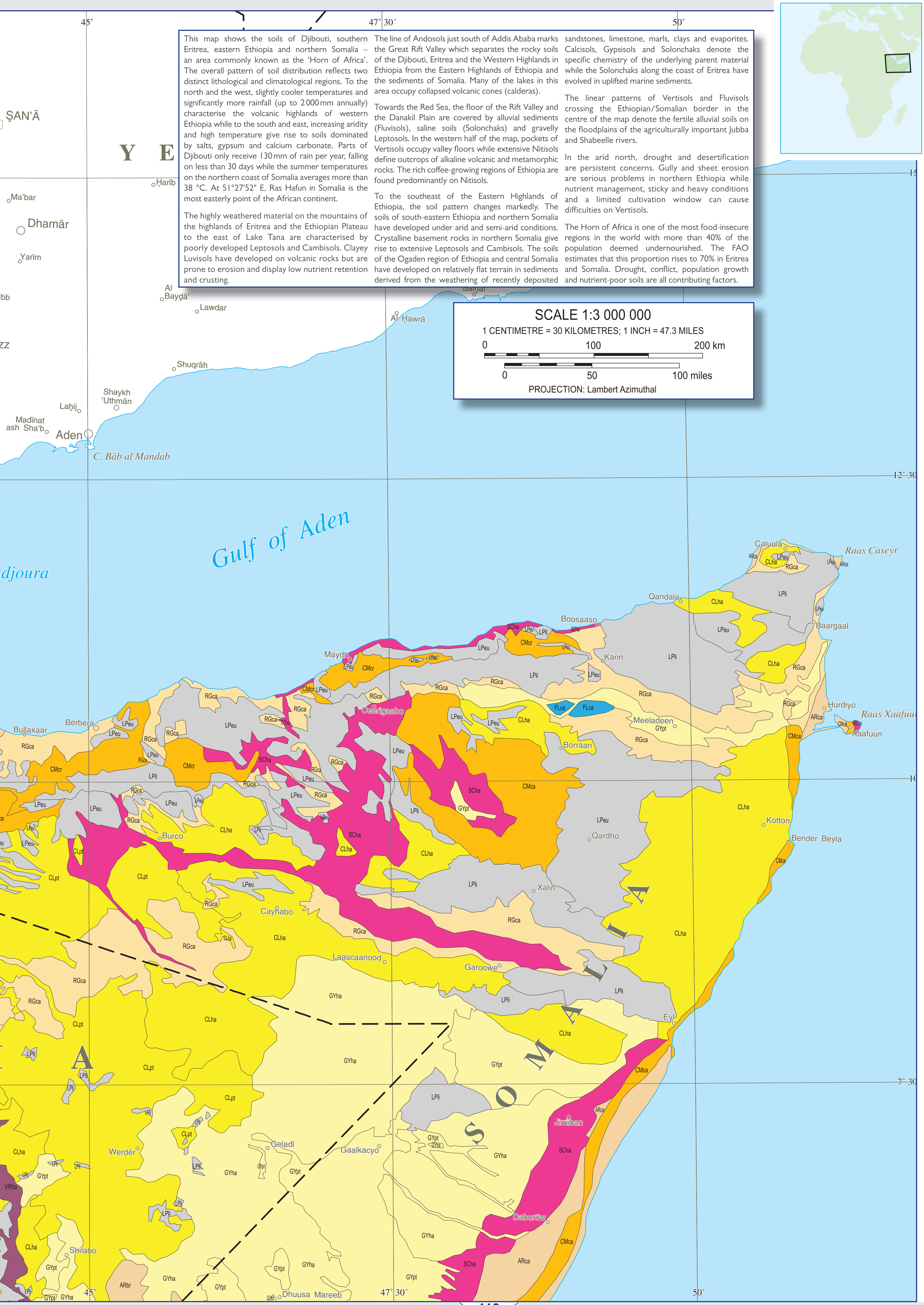
SCALE 1:3 000 000

1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES

0 100 200 km

0 50 100 miles

PROJECTION: Lambert Azimuthal



113

96

This map shows the soils of eastern Liberia, eastern Guinea, the Côte D'Ivoire, Ghana, Togo, Benin and southwest Nigeria. The pattern of soil distribution on the map reflects the intense weathering of the rocks of the West African Shield, a stable 3 billion year old rock formation, under hot and humid equatorial conditions. The large expanse of water lying along the Greenwich Meridian in Ghana is Lake Volta, the largest reservoir by surface area in the world (about 8 500 km²).

While the south-western part of the map has a typical hot and humid equatorial climate with extensive evergreen rainforest, the majority of the region has a humid savannah environment. Precipitation levels increase significantly to the south and west with the southern parts of Liberia receiving some of the highest rainfall in Africa (approaching 3 000 mm annually). Average monthly temperature varies between 25-35°C).

To the north and east, the humid savannah climate is characterised by the dry Harmattan wind (which blows from the northeast during, winter), a dry season lasting from about November to March and annual precipitation of around 1 500 mm. The shrubby grasslands of the north become more wooded towards the south, eventually grading into forest. The boundary between the savannah and forest is increasingly being cleared for rain-fed cultivation.

The distribution of soil types reflects the interplay between the underlying parent material, topography and climate. In the west, the intense chemical weathering of the West African Craton gives rise to a gently undulating landscape where extensive acidic Acrisols have developed on granites and schists while Alisols occur on more basic materials. Clay- and iron-rich Plinthosols denote more level terrain. On the alluvial sediments of the coastal plain of the Côte D'Ivoire, Liberia and Togo, deep, red or yellow Ferralsols have formed under rainforest.

The valley of the River Volta, denoted by alluvial Fluvisols, marks the eastern boundary of the West African Craton. To the east, less acid Lixisols with leached, clay-rich subsoils occur in strongly-weathered, fine textured materials under natural savannah or open woodland vegetation. Nitisols are found on gentle slopes between the coastal plains and interior plateau of Benin, Nigeria and Togo while iron-rich Plinthosols also indicate level or gently undulating landscapes. In Nigeria, bare, isolated mountains known as inslebergs give rise to individual patches of Leptosols.

Along the coast sandbars and lagoons or deltas give rise to Arenosols and Gleysols respectively. The Gleysols and Fluvisols on the coast at the extreme right of the map denote the beginning of the delta of the River Niger.

Soil conservation is extremely important in this region. While low fertility, high levels of aluminium and phosphate fixation affect the use of the soil, heavy rainfall can cause serious erosion, especially following forest clearance.

98

GHANA
TOGO
BENIN
NIGERIA
Gulf of Guinea
Bight of Benin
L. Volta
White Volta
Volta
C. Three Points
Léo
Tumu
Navrongo
Bolgatanga
Walewale
Gambaga
Funsi
Dapaong
Sansanné-Mango
Koumongou
Tanguiéta
Natitingou
Kandi
Ségbana
Beroubouaye
Bembèrèkè
Ndali
Nikki
Wawa
Kaiama
Mokwa
Jebba
Kandé
Kara
Djougou
Bassar
Sokodé
Tchamba
Bassila
Savelugu
Daboya
Tamale
Yendi
Zabzugu
Damongo
Salaga
Kintampo
Wenchi
Sunyani
Ejura
Kumasi
Nkawkaw
Obuasi
Dunkwa
Kade
Tafo
Koforidua
Oda
Nsawam
Foso
ACCRA
Téma
Winneba
Cape Coast
Tarkwa
Nsuta
Sekondi-Takoradi
Axim
Sotouboua
Atakpamé
Jasikan
Kpalimé
Kra
Ho
Tsévié
LOMÉ
Vogan
Aného
Keta
Ada
Parakou
Tchaourou
Kilibo
Savé
Savalou
Okuta
Ilesha
Kishi
Igboho
Igbetti
Shaki
Ilorin
Offa
Ogbomosho
Iseyin
Ilobu
Oyo
Oshogbo
Ede
Iwo
Ila
Effon-Alaiye
Ado Ekiti
Ilesa
Ile Ife
Ikire
IBADAN
Ilawe-Ekiti
Akure
Ondo
Abeokuta
Abomey
Pobè
Ilaro
Sagamu
Ijebu Ode
Kétou
Allada
Sakété
Ado
Ikeja
Ikorodu
PORTO NOVO
Ouidah
Cotonou
Mushin
LAGOS
Okitipupa
0°
2° 30´
5°
SCALE 1:3 000 000
1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES
0
100
200 km
0
50
100 miles
PROJECTION: Lambert Azimuthal

99

108

107

This map shows the soils of São Tomé and Príncipe, southern Cameroon, southern Central African Republic, Congo, the western part of the Democratic Republic of the Congo, Equatorial Guinea and Gabon. The equator runs horizontally through the middle of the map. The major geographical features of the region are the Niger Delta and the vast Congo Basin.

The climate is classic equatorial, typified by constantly heavy precipitation, high temperatures and high humidity. Precipitation averages more than 2 000 mm and in places can be much higher (> 3 000 mm). Debundscha at the foot of Mount Cameroon is regarded as the wettest place in Africa with a staggering 10 000 mm of rainfall annually. Seasonal temperatures are relatively stable (22-30°C) with significantly greater variation between day and night, while along the coast the sea has a considerable cooling effect. The average daily humidity is about 80 percent.

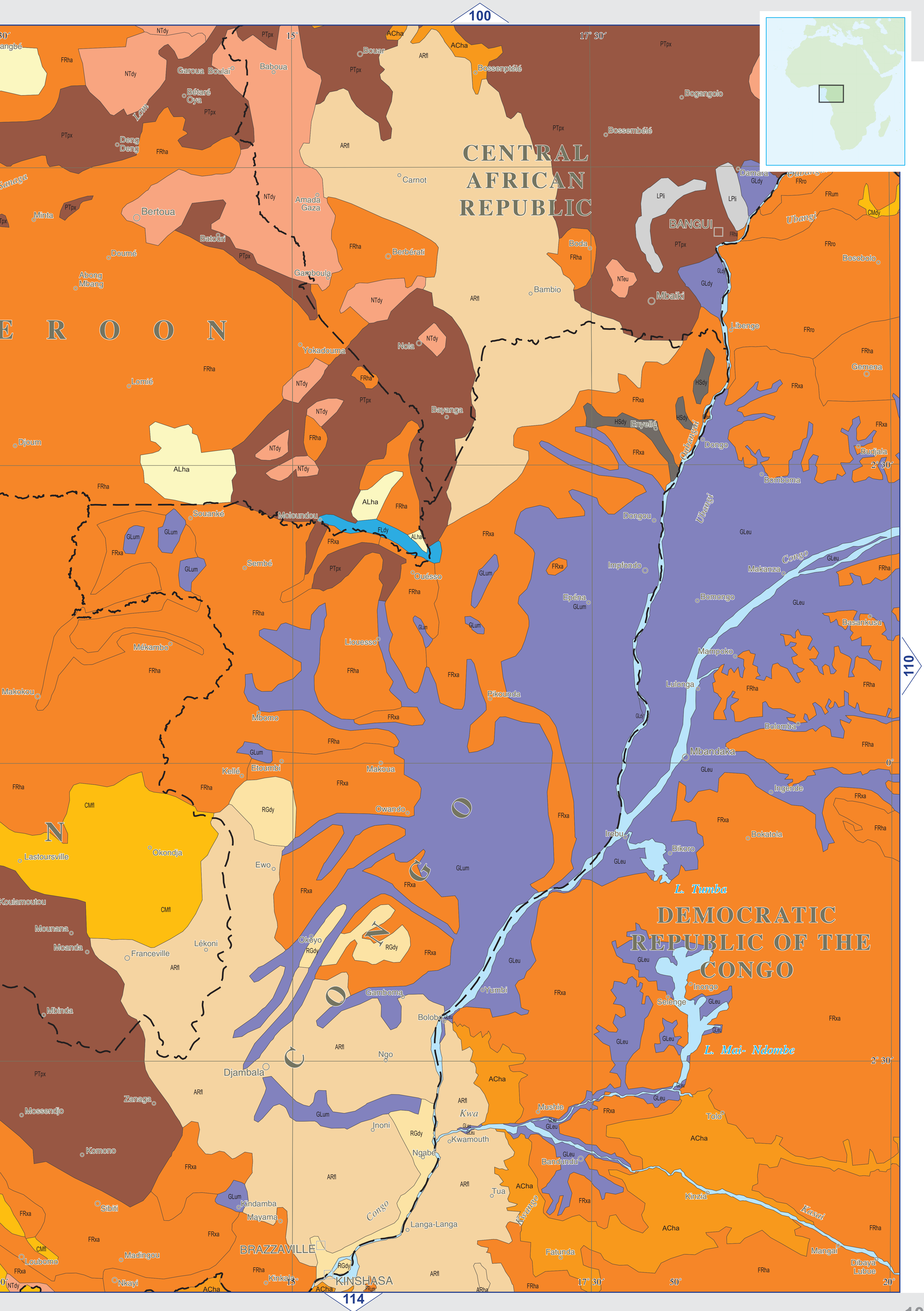
The vegetation is almost exclusively broadleaved, evergreen rainforest, grading into deciduous African Oak forests where precipitation levels are lower. Dense growths of broadleaved trees form a closed upper canopy over an undergrowth of leafy plants and vines. Coconut palms and mangrove forests grow in the coastal regions.

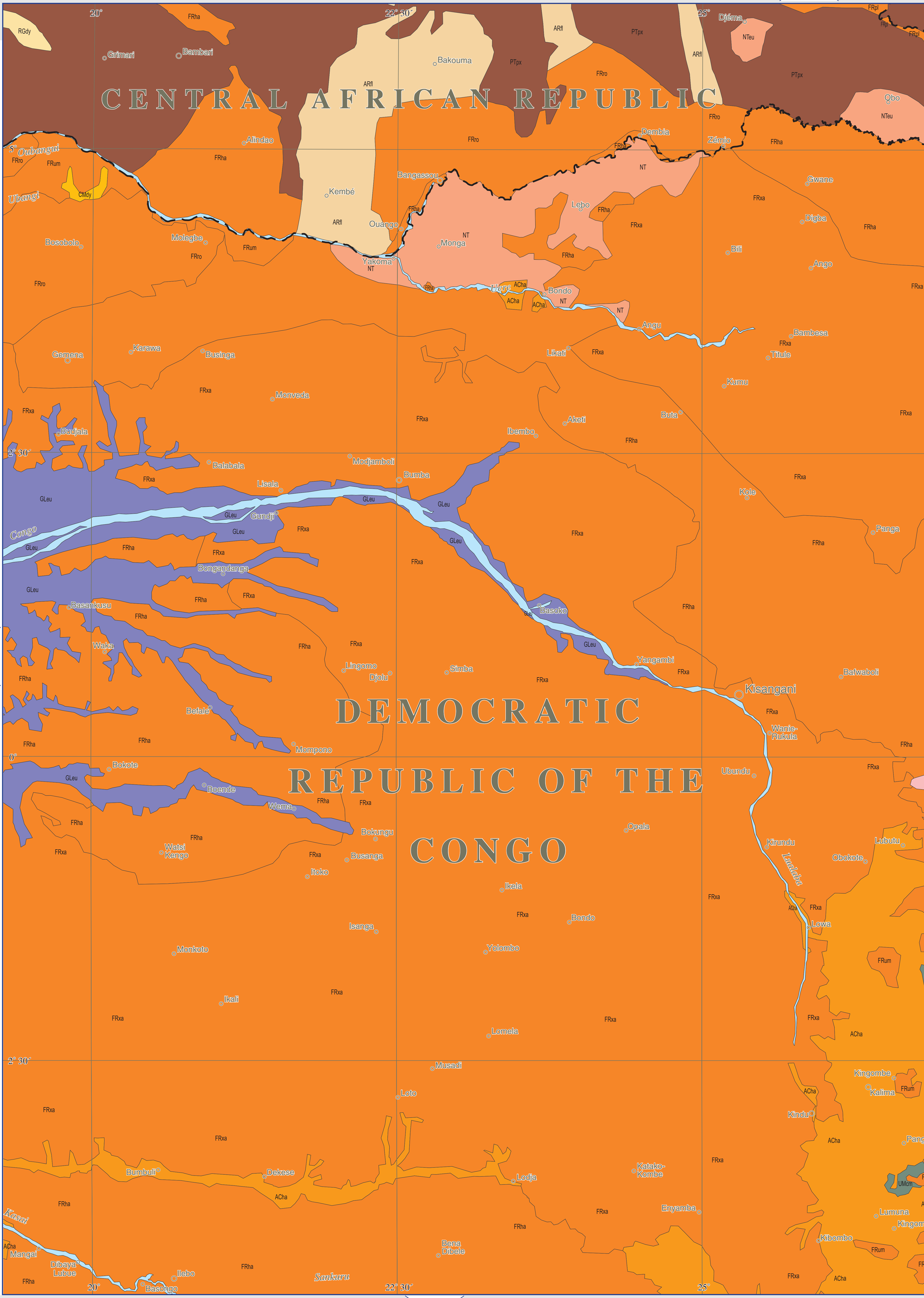
The pattern of soil types on the map reflects the long and intense weathering of the Congo Shield, an ancient, stable rock formation. The dominant soil are Ferralsols, the classic red or yellow deeply weathered soils of the tropics. Ferralsols are coarse-grained soils containing sand and gravel with high levels of iron and aluminium sesquioxides. Organic matter and nutrient levels are low because plant remains are rapidly decomposed by bacterial action in the hot and humid climate before it can accumulate as humus in the soil. Topsoil erosion due to heavy rainfall, and especially after deforestation, is a major problem. Iron- and clay-rich Plinthosols indicate soil formation in level or gently undulating landscapes affected by groundwater movements while Nitisols are found on gentle slopes between the coastal plains and interior plateau of Nigeria. Much of Gabon is characterised by a series of granite plateaus on which weakly developed Cambisols have formed.

Sandbars, lagoons and deltas along the coast give rise to Arenosols and Gleysols. Along the coast of Cameroon and Gabon, mangrove forests give rise to Tidalic Fluvisols. A distinctive area is the delta of the River Niger in the Gulf of Guinea. Gleysols highlight low-lying marshy areas which give rise to waterlogged soils with Fluvisols occurring on the depositional front of the delta. Deeply weathered Ferralsols are found in sandy alluvium sediments. The Gulf of Guinea is actually a major tectonic rift, similar to the Great Rift Valley of Eastern Africa. Consequently, the volcanic activity which created the islands of São Tomé and Príncipe and Mount Cameroon (one of Africa's largest volcanoes), gives rise to Andosols.

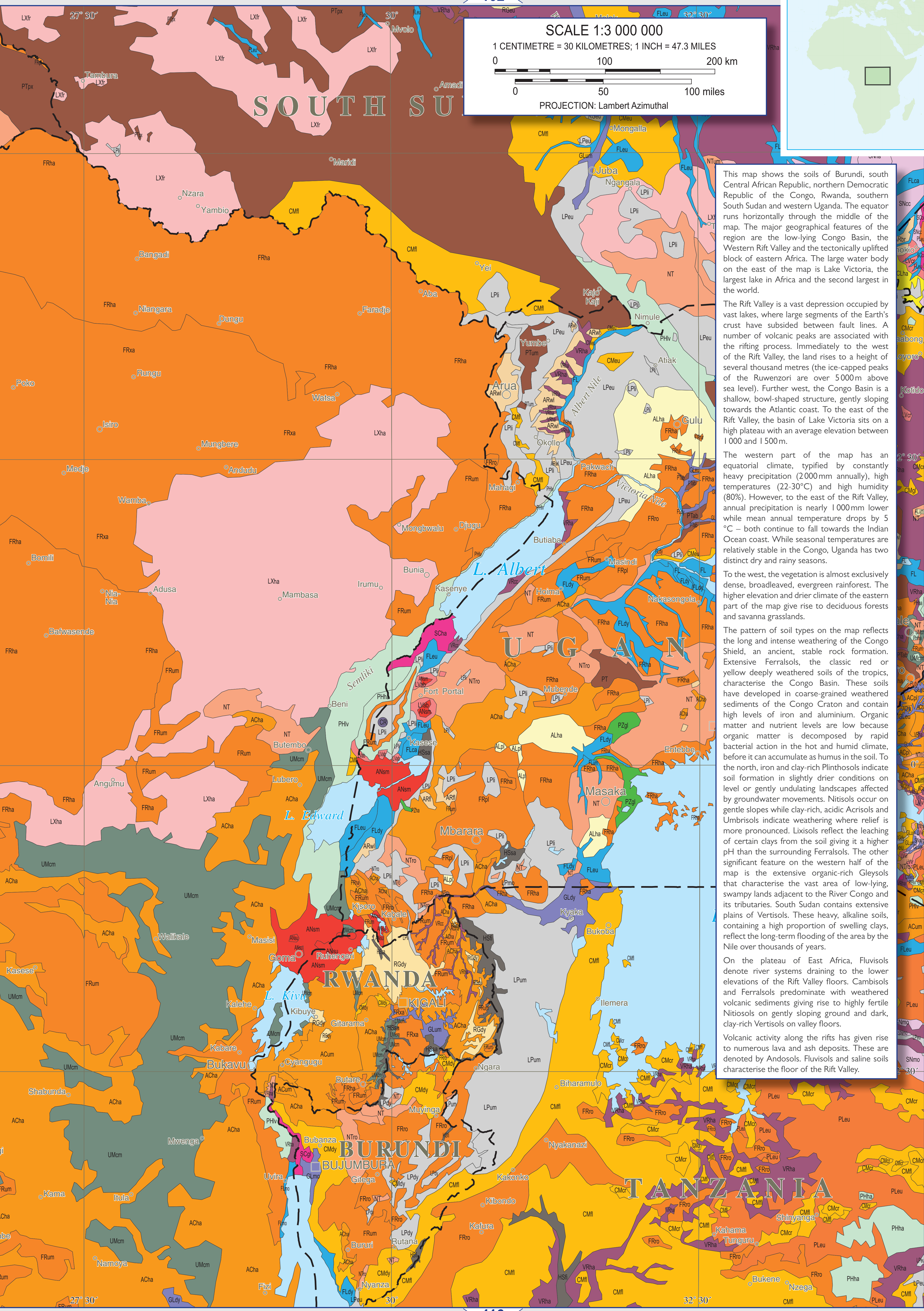
The other significant feature on the map is the extensive organic-rich Gleysols that characterise the vast area of low-lying, swampy lands adjacent to the River Congo and its tributaries (with a length of 4 700 km, the Congo is the continent's second longest river after the Nile).

Because of their intrinsic lack of nutrients, many soils are heavily dependent upon organic matter supplied by the vegetation cover. In this case, there is a fragile balance between vegetation and soil fertility, which may be destroyed by clearance, erosion, fire or overuse.


100
110
114
CENTRAL AFRICAN REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
E R O O N
N
O
C O N G O
BANGUI
BRAZZAVILLE
KINSHASA
Bouar
Bossentélé
Bogangolo
Bossembélé
Baboua
Garoua Boulaï
Bétaré Oya
Deng Deng
Carnot
Amada Gaza
Bertoua
Batouri
Minta
Doumé
Abong Mbang
Berbérati
Gamboula
Boda
Bambio
Mbaïki
Damara
Bosobolo
Libenge
Gemena
Yokadouma
Nola
Bayanga
Lomié
Djoum
Enyellé
Dongo
Budjala
Bomboma
Souanké
Moloundou
Dongou
Sembé
Ouésso
Impfondo
Epéna
Makanza
Bomongo
Basankusu
Mékambo
Liouesso
Mampoko
Lulonga
Makokou
Pikounda
Mbomo
Bolomba
Mbandaka
Kellé
Etoumbi
Makoua
Ingende
Owando
Irebu
Bikoro
Bokatola
Lastoursville
Okondja
Ewo
L. Tumba
Koulamoutou
Mounana
Moanda
Franceville
Lékoni
Okoyo
Gamboma
Inongo
Selenge
Yumbi
Bolobo
Mbinda
L. Mai- Ndombe
Ngo
Djambala
Zanaga
Mossendjo
Mushie
Tolo
Kwa
Inoni
Kwamouth
Ngabé
Komono
Bandundu
Tua
Kinzia
Sibiti
Kindamba
Mayama
Langa-Langa
Kwango
Kasai
Madingou
Loubomo
Nkayi
Kinkala
Fatunda
Mangai
Dibaya Lubue
Sanaga
Lom
Oubangui
Ubangi
Congo
17° 30´
15°
2° 30´
0°
20°
50°


101
109
114
CENTRAL AFRICAN REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
20°
22° 30'
25°
5°
2° 30'
0°
2° 30'
Oubangui
Ubangi
Uele
Congo
Lualaba
Kasai
Sankuru
Grimari
Bambari
Bakouma
Djéma
Obo
Zémio
Dembia
Alindao
Bangassou
Kembé
Ouango
Yakoma
Monga
Lebo
Bondo
Angu
Gwane
Digba
Bili
Ango
Bambesa
Titule
Kumu
Buta
Aketi
Likati
Ibembo
Bosobolo
Molegbe
Gemena
Karawa
Businga
Monveda
Budjala
Balabala
Modjamboli
Bumba
Lisala
Gundji
Bongandanga
Basankusu
Waka
Befale
Mompono
Lingomo
Djolu
Simba
Basoko
Yangambi
Kisangani
Kole
Panga
Bafwaboli
Wanie-Rukula
Ubundu
Bokote
Boende
Wema
Bokungu
Busanga
Itoko
Watsi Kengo
Opala
Kirundu
Lubutu
Obokote
Lowa
Ikela
Bondo
Isanga
Yolombo
Monkoto
Ikali
Lomela
Musadi
Loto
Kingombe
Kalima
Kindu
Bumbuli
Dekese
Lodja
Katako-Kombe
Enyamba
Lumuna
Kibombo
Mangai
Dibaya Lubue
Ilebo
Basongo
Bena Dibele
RGdy
FRha
FRro
FRum
FRxa
CMdy
ARfl
PTpx
NTeu
NT
ACha
GLeu
UMom

102



This map shows the soils of Burundi, south Central African Republic, northern Democratic Republic of the Congo, Rwanda, southern South Sudan and western Uganda. The equator runs horizontally through the middle of the map. The major geographical features of the region are the low-lying Congo Basin, the Western Rift Valley and the tectonically uplifted block of eastern Africa. The large water body on the east of the map is Lake Victoria, the largest lake in Africa and the second largest in the world.

The Rift Valley is a vast depression occupied by vast lakes, where large segments of the Earth's crust have subsided between fault lines. A number of volcanic peaks are associated with the rifting process. Immediately to the west of the Rift Valley, the land rises to a height of several thousand metres (the ice-capped peaks of the Ruwenzori are over 5 000 m above sea level). Further west, the Congo Basin is a shallow, bowl-shaped structure, gently sloping towards the Atlantic coast. To the east of the Rift Valley, the basin of Lake Victoria sits on a high plateau with an average elevation between 1 000 and 1 500 m.

The western part of the map has an equatorial climate, typified by constantly heavy precipitation (2 000 mm annually), high temperatures (22-30°C) and high humidity (80%). However, to the east of the Rift Valley, annual precipitation is nearly 1 000 mm lower while mean annual temperature drops by 5 °C – both continue to fall towards the Indian Ocean coast. While seasonal temperatures are relatively stable in the Congo, Uganda has two distinct dry and rainy seasons.

To the west, the vegetation is almost exclusively dense, broadleaved, evergreen rainforest. The higher elevation and drier climate of the eastern part of the map give rise to deciduous forests and savanna grasslands.

The pattern of soil types on the map reflects the long and intense weathering of the Congo Shield, an ancient, stable rock formation. Extensive Ferralsols, the classic red or yellow deeply weathered soils of the tropics, characterise the Congo Basin. These soils have developed in coarse-grained weathered sediments of the Congo Craton and contain high levels of iron and aluminium. Organic matter and nutrient levels are low because organic matter is decomposed by rapid bacterial action in the hot and humid climate, before it can accumulate as humus in the soil. To the north, iron and clay-rich Plinthosols indicate soil formation in slightly drier conditions on level or gently undulating landscapes affected by groundwater movements. Nitisols occur on gentle slopes while clay-rich, acidic Acrisols and Umbrisols indicate weathering where relief is more pronounced. Lixisols reflect the leaching of certain clays from the soil giving it a higher pH than the surrounding Ferralsols. The other significant feature on the western half of the map is the extensive organic-rich Gleysols that characterise the vast area of low-lying, swampy lands adjacent to the River Congo and its tributaries. South Sudan contains extensive plains of Vertisols. These heavy, alkaline soils, containing a high proportion of swelling clays, reflect the long-term flooding of the area by the Nile over thousands of years.

On the plateau of East Africa, Fluvisols denote river systems draining to the lower elevations of the Rift Valley floors. Cambisols and Ferralsols predominate with weathered volcanic sediments giving rise to highly fertile Nitiosols on gently sloping ground and dark, clay-rich Vertisols on valley floors.

Volcanic activity along the rifts has given rise to numerous lava and ash deposits. These are denoted by Andosols. Fluvisols and saline soils characterise the floor of the Rift Valley.

112

116

104

111


ETHIOPIA
SOUTH SUDAN
KENYA
TANZANIA
L. Turkana
Maji
Arba Minch
Bako
Kibre Mengist
Negele
Filtu
Mega
Moyale
Lokichokio
Kaabong
Loyoro
Kotido
Moroto
Lokichar
Kaputir
Amudat
North Horr
South Horr
Baragoi
Marsabit
Choba
Laisamis
Buna
El Wak
Wajir
Mbale
Tororo
Busia
Kitale
Webuye
Eldoret
Kakamega
Butere
Maralal
Wamba
Archer's Post
Isiolo
Merti
Habaswein
Mado Gashi
Liboi
Equator
Kisumu
Kericho
Kisii
Nakuru
Solai
Nanyuki
Meru
Gilgil
Naivasha
Nyeri
Embu
Thika
Narok
NAIROBI
Ngong
Machakos
Kitui
Garissa
Musoma
Magadi
Kajiado
Namanga
Kakya
Lamu
Malindi
Arusha
Moshi
Taveta
Mwatate
Mariakani
Mombasa
Kilindini
35°
37° 30'
40°
5°
2° 30' N
0°
2° 30' S

117

This map shows the incredible variety of soils covering southern Ethiopia, Kenya, southern Somalia and northern Tanzania. The major geographical feature of the region is the Eastern Rift Valley that runs north-south through the left-hand side of the map. The diversity of soil types is due to the range of geological and climatic conditions of the area and the tectonically uplifted block of eastern Africa.

The Eastern Rift Valley is a vast depression where large segments of the Earth's crust have subsided between fault lines caused by the separation of Africa and the Arabian Peninsula. The valley floor is occupied by several large, shallow lakes and a number of volcanic peaks are associated with the rifting process. Kilimanjaro, at 5 895 m Africa's highest mountain and volcano, lies just south of the equator on the border of Kenya and Tanzania. Either side of the valley, the land rises by around 600 m to a high plateau with an elevation of 1 000 - 1 500 m above sea level. The Kenyan Highlands are one of the most successful agricultural production regions in Africa. To the northeast, the plateau falls away to a low, flat, semi-arid plain that extends across the Ethiopian/Kenyan border to the Indian Ocean. Olduvai Gorge, regarded as the birthplace of human beings, is located in volcanic sediments of northern Tanzania.

The climate of the region ranges from humid savannah in the west and dry savannah in the centre to semi-arid in southern Somalia. This is matched by a gradual decrease in vegetation cover. Annual temperatures are generally high in the Rift Valley and coastal plain but are moderated by elevation on the plateau. While the Rift Valley floor is dry, the highlands receive around 700 mm of rainfall annually. While the more tropical Kenyan coast receives slightly higher rainfall, the area between the sea and the plateau is notably drier. To the northwest, the coastal and inland plains of Ethiopia and northern Kenya are quite arid with irregular annual rainfall (around 250 mm) and annual temperatures in the order of 30°C.

The distribution of soil types on the map can be divided into two regions east and west of the 38°E meridian. To the west, the soils reflect the weathering of volcanic and uplifted sediments. Extensive lava deposits have produced fertile and sandy-loam Andosols while Planosols interspersed with Luvisols and productive clay-rich Vertisols (the latter tending to develop on the level ground of valley floors). On the slopes of volcanoes (e.g. Mount Elgon), fertile Nitisols are well known for coffee and tea production while the extensive grasslands of the Serengeti and Mara Plains give rise to organic and lime-rich Phaeozems. To the north, the semi-arid basin of Lake Turkana is characterised by Calcisols, Cambisols and Regosols while increasing temperatures are also denoted by large expanses of sodic Solonetz.

To the east of the 38°E meridian, the land drops in elevation and a large, predominantly sandy, plain extends towards the Indian Ocean coastlines of Somalia and northern Kenya. This coarse grained material gives rise to Arenosols and red coloured Ferralsols while the evaporation of saline groundwater gives rise to widespread occurrences of Solonetz. Lixisols reflect less acid soils in areas with a pronounced dry season. Fluvisols denote the alluvial sediments of river systems draining from the plateau and dark, clayey Vertisols tend to develop on valley floors in sediments derived from the weathering of basic volcanic material on the plateau.

The linear patterns of Vertisols and Fluvisols crossing the southern Somalian coastal plain define the fertile alluvial soils on the floodplains of the agriculturally important Jubba and Shabeelle rivers, the latter gives rise to the fertile marsh lands and plains around Mogadishu. The Arenosols flanking much of the Somalian coastline is a vast belt of ancient dunes that stretches for more than 1 000 km.

Many of the soils on this map are subject to widespread erosion largely due to the lack of tree cover, overgrazing and cultivation. The issue is particularly pronounced in the more arid and semi-arid regions. The Horn of Africa is one of the most food-insecure regions in the world with more than 40% of the population deemed undernourished. The FAO estimates that this proportion rises to 70% in Eritrea and Somalia. Drought, conflict, population growth and nutrient-poor soils are all contributing factors.

The very dense soil patterns for Kenya reflects a more detailed soil mapping base. Such a level of information should be the minimum goal for the other African countries (see also Plates 21, 23 and 24).

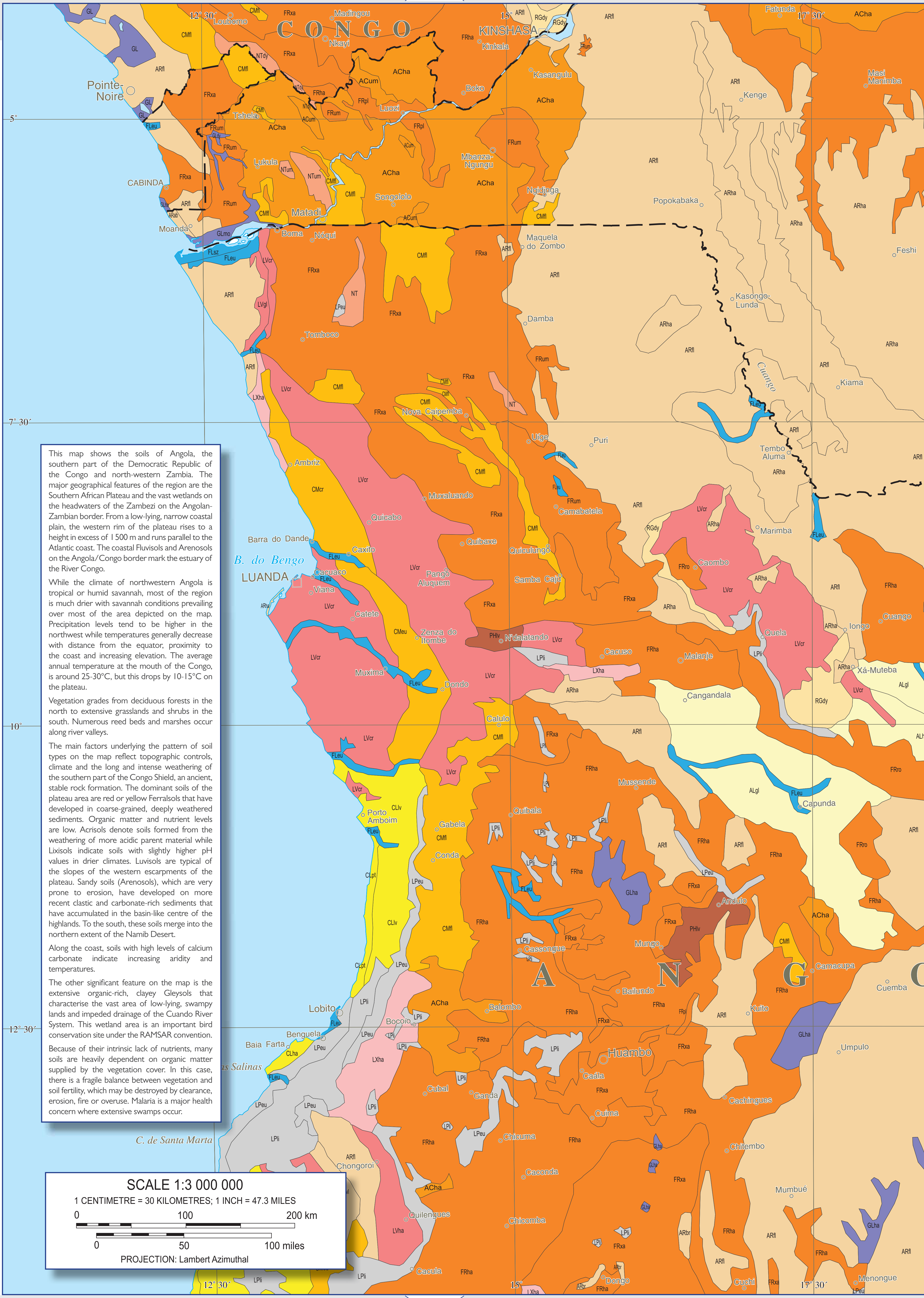
SCALE 1:3 000 000

1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES

0 100 200 km

0 50 100 miles

PROJECTION: Lambert Azimuthal



This map shows the soils of Angola, the southern part of the Democratic Republic of the Congo and north-western Zambia. The major geographical features of the region are the Southern African Plateau and the vast wetlands on the headwaters of the Zambezi on the Angolan-Zambian border. From a low-lying, narrow coastal plain, the western rim of the plateau rises to a height in excess of 1 500 m and runs parallel to the Atlantic coast. The coastal Fluvisols and Arenosols on the Angola/Congo border mark the estuary of the River Congo.

While the climate of northwestern Angola is tropical or humid savannah, most of the region is much drier with savannah conditions prevailing over most of the area depicted on the map. Precipitation levels tend to be higher in the northwest while temperatures generally decrease with distance from the equator, proximity to the coast and increasing elevation. The average annual temperature at the mouth of the Congo, is around 25-30°C, but this drops by 10-15°C on the plateau.

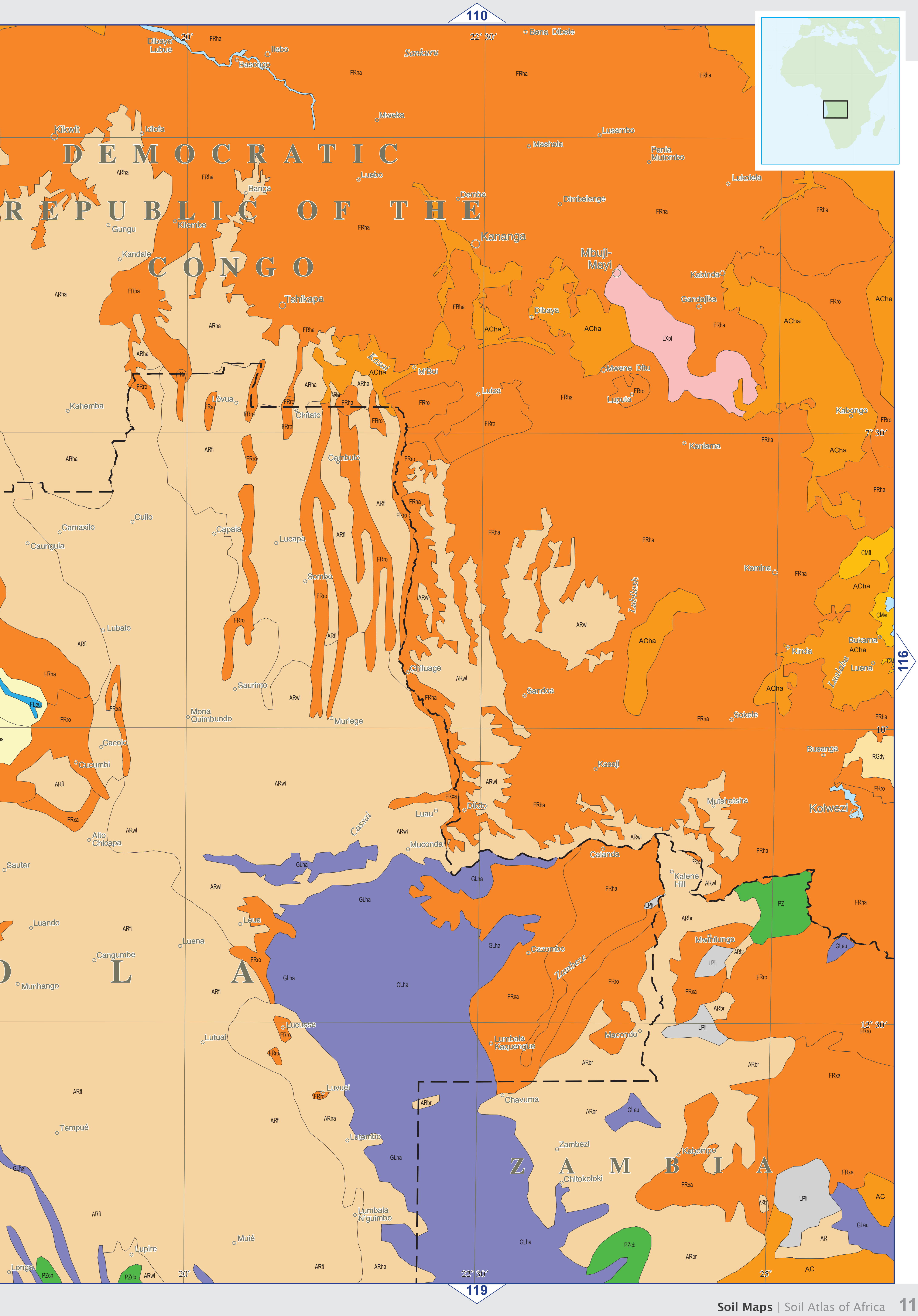
Vegetation grades from deciduous forests in the north to extensive grasslands and shrubs in the south. Numerous reed beds and marshes occur along river valleys.

The main factors underlying the pattern of soil types on the map reflect topographic controls, climate and the long and intense weathering of the southern part of the Congo Shield, an ancient, stable rock formation. The dominant soils of the plateau area are red or yellow Ferralsols that have developed in coarse-grained, deeply weathered sediments. Organic matter and nutrient levels are low. Acrisols denote soils formed from the weathering of more acidic parent material while Lixisols indicate soils with slightly higher pH values in drier climates. Luvisols are typical of the slopes of the western escarpments of the plateau. Sandy soils (Arenosols), which are very prone to erosion, have developed on more recent clastic and carbonate-rich sediments that have accumulated in the basin-like centre of the highlands. To the south, these soils merge into the northern extent of the Namib Desert.

Along the coast, soils with high levels of calcium carbonate indicate increasing aridity and temperatures.

The other significant feature on the map is the extensive organic-rich, clayey Gleysols that characterise the vast area of low-lying, swampy lands and impeded drainage of the Cuando River System. This wetland area is an important bird conservation site under the RAMSAR convention.

Because of their intrinsic lack of nutrients, many soils are heavily dependent on organic matter supplied by the vegetation cover. In this case, there is a fragile balance between vegetation and soil fertility, which may be destroyed by clearance, erosion, fire or overuse. Malaria is a major health concern where extensive swamps occur.


110
116
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20°
22° 30´
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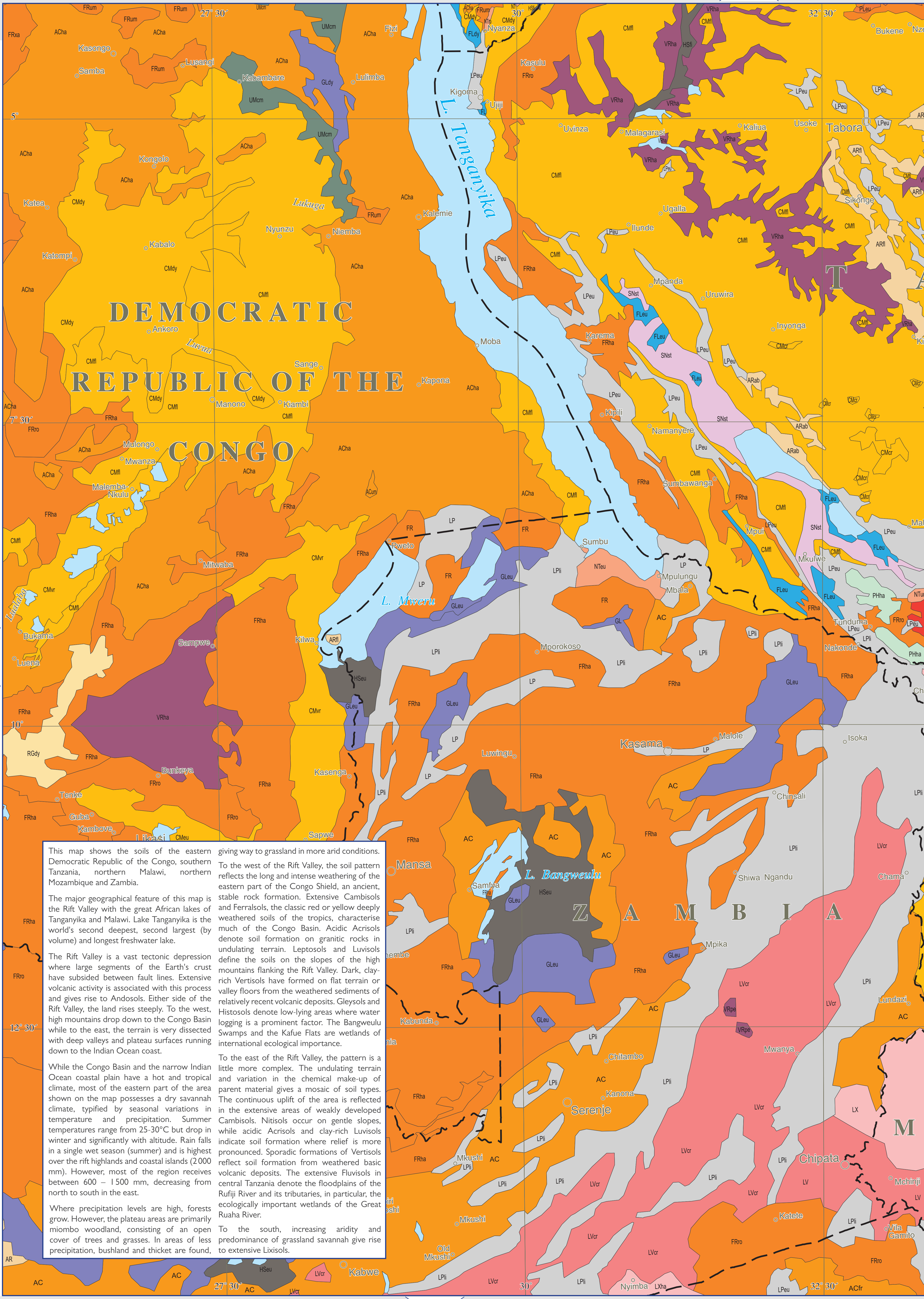
7° 30´
10°
12° 30´
DEMOCRATIC
REPUBLIC OF THE
CONGO
ZAMBIA
L
A
Dibaya Lubue
Ilebo
Basongo
Sankuru
Bena Dibele
Mweka
Kikwit
Idiofa
Lusambo
Mashala
Pania Mutombo
Lukolela
Luebo
Banga
Demba
Dimbelenge
Kilembe
Gungu
Kananga
Mbuji-Mayi
Kandale
Kabinda
Tshikapa
Gandajika
Dibaya
Kasai
M'Boi
Mwene Ditu
Lupula
Luiza
Lóvua
Chitato
Kahemba
Kabongo
Kaniama
Cambulo
Cuilo
Camaxilo
Caungula
Capaia
Lucapa
Kamina
Sombo
Lubilash
Lubalo
Bukama
Kinda
Luena
Lualaba
Chiluage
Sandoa
Saurimo
Mona Quimbundo
Muriege
Sokele
Cacolo
Busanga
Cucumbi
Kasaji
Kolwezi
Mutshatsha
Dilolo
Luau
Cassai
Alto Chicapa
Muconda
Calanda
Sautar
Kalene Hill
Mwinilunga
Luando
Leua
Luena
Cazombo
Cangumbe
Zambeze
Munhango
Lucusse
Macondo
Lutuai
Lumbala Kaquengue
Chavuma
Luvuei
Tempué
Lutembo
Zambezi
Kabompo
Chitokoloki
Lumbala N'guimbo
Muié
Lupire
Longa
FRha
ARha
ACha
FRro
FRxa
ARfl
ARwl
ARbr
LXpl
CMfl
CMvr
RGdy
FLeu
GLha
GLeu
LPli
PZ
PZcb
AC
AR

111



This map shows the soils of the eastern Democratic Republic of the Congo, southern Tanzania, northern Malawi, northern Mozambique and Zambia.

The major geographical feature of this map is the Rift Valley with the great African lakes of Tanganyika and Malawi. Lake Tanganyika is the world's second deepest, second largest (by volume) and longest freshwater lake.

The Rift Valley is a vast tectonic depression where large segments of the Earth's crust have subsided between fault lines. Extensive volcanic activity is associated with this process and gives rise to Andosols. Either side of the Rift Valley, the land rises steeply. To the west, high mountains drop down to the Congo Basin while to the east, the terrain is very dissected with deep valleys and plateau surfaces running down to the Indian Ocean coast.

While the Congo Basin and the narrow Indian Ocean coastal plain have a hot and tropical climate, most of the eastern part of the area shown on the map possesses a dry savannah climate, typified by seasonal variations in temperature and precipitation. Summer temperatures range from 25-30°C but drop in winter and significantly with altitude. Rain falls in a single wet season (November to April) and is highest over the rift highlands and coastal islands (2 000 mm). However, most of the region receives between 600 – 1 500 mm, decreasing from north to south in the east.

Where precipitation levels are high, forests grow. However, the plateau areas are primarily miombo woodland, consisting of an open cover of trees and grasses. In areas of less precipitation, bushland and thicket are found, giving way to grassland in more arid conditions.

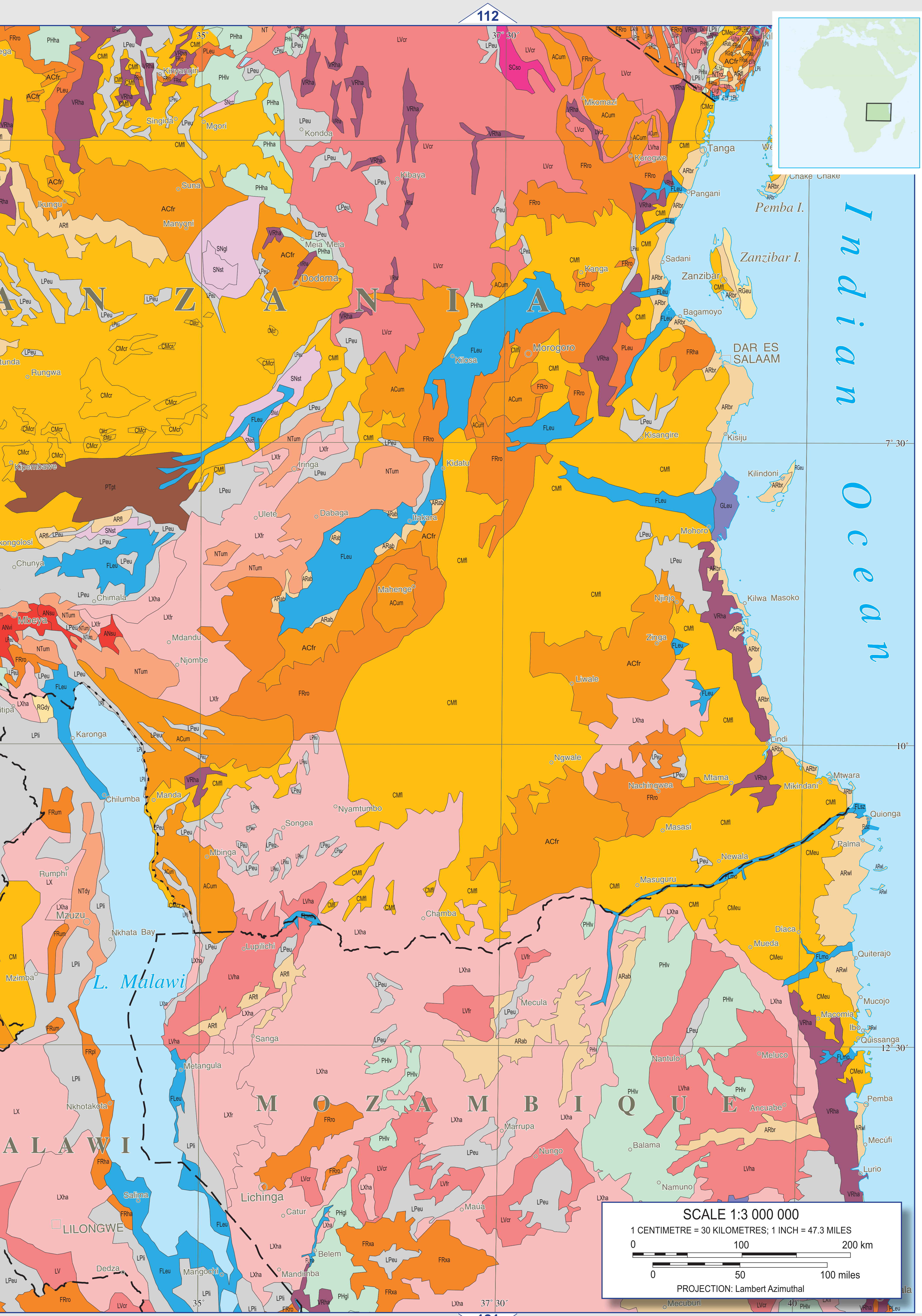
To the west of the Rift Valley, the soil pattern reflects the long and intense weathering of the eastern part of the Congo Shield, an ancient, stable rock formation. Extensive Cambisols and Ferralsols, the classic red or yellow deeply weathered soils of the tropics, characterise much of the Congo Basin. Acidic Acrisols denote soil formation on granitic rocks in undulating terrain. Leptosols and Luvisols define the soils on the slopes of the high mountains flanking the Rift Valley. Dark, clay-rich Vertisols have formed on flat terrain or valley floors from the weathered sediments of relatively recent volcanic deposits. Gleysols and Histosols denote low-lying areas where water logging is a prominent factor. The Bangweulu Swamps and the Kafue Flats are wetlands of international ecological importance.

To the east of the Rift Valley, the pattern is a little more complex. The undulating terrain and variation in the chemical make-up of parent material gives a mosaic of soil types. The continuous uplift of the area is reflected in the extensive areas of weakly developed Cambisols. Nitisols occur on gentle slopes, while acidic Acrisols and clay-rich Luvisols indicate soil formation where relief is more pronounced. Sporadic formations of Vertisols reflect soil formation from weathered basic volcanic deposits. The extensive Fluvisols in central Tanzania denote the floodplains of the Rufiji River and its tributaries, in particular, the ecologically important wetlands of the Great Ruaha River.

To the south, increasing aridity and predominance of grassland savannah give rise to extensive Lixisols.

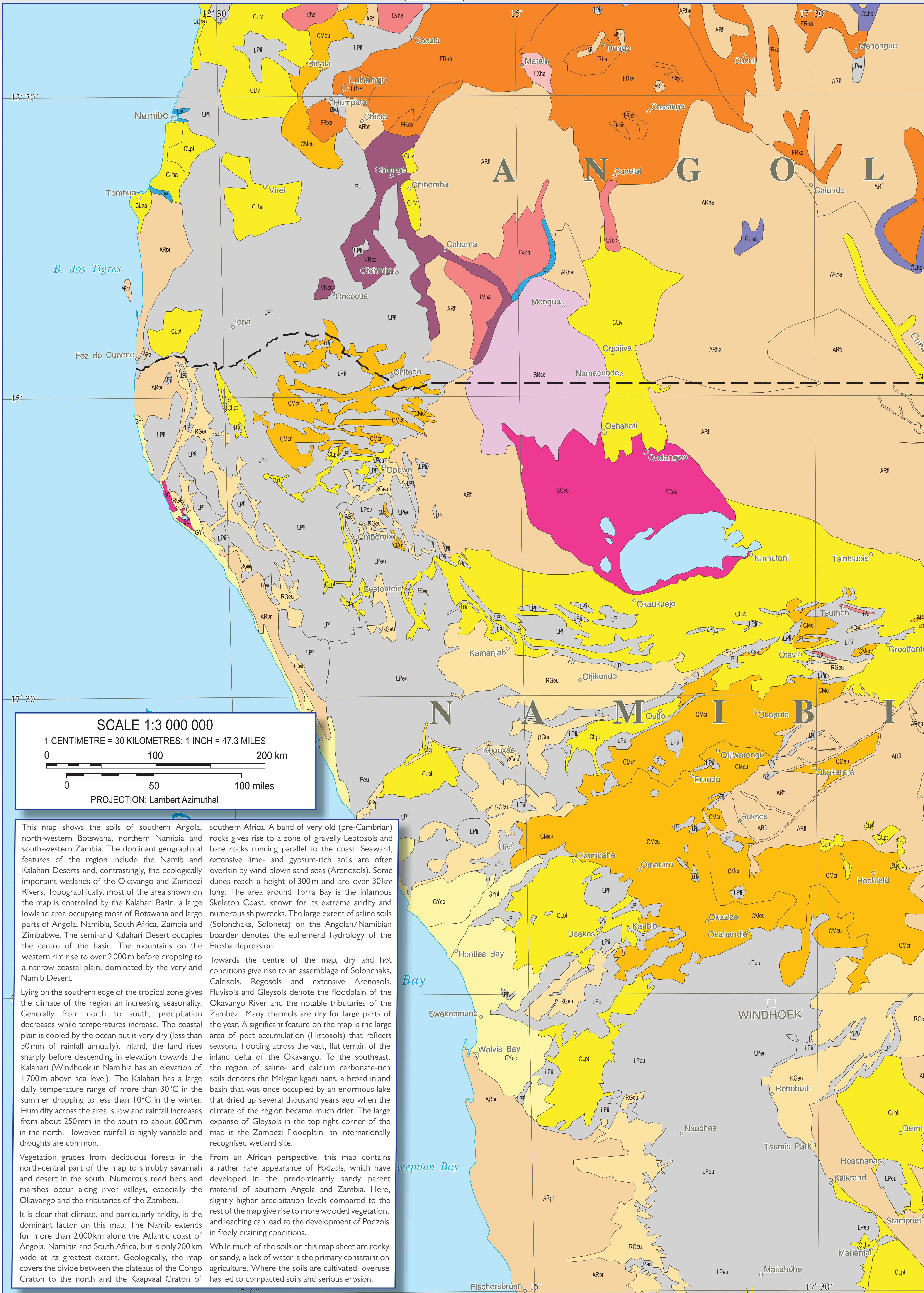
115

120


T A N Z A N I A
M O Z A M B I Q U E
M A L A W I
Indian Ocean
L. Malawi
Pemba I.
Zanzibar I.
DAR ES SALAAM
Tanga
Pangani
Chake Chake
Zanzibar
Sadani
Bagamoyo
Kisiju
Kilindoni
Mohoro
Kilwa Masoko
Lindi
Mtwara
Mikindani
Quionga
Palma
Quiterajo
Mucojo
Macomia
Ibo
Quissanga
Pemba
Mecúfi
Lurio
Meluco
Ancuabe
Mecuburi
Namuno
Balama
Nungo
Marrupa
Maúa
Mecula
Lichinga
Catur
Belem
Mandimba
Sanga
Metangula
Lupilichi
Chamba
Masuguru
Newala
Masasi
Nachingwea
Mtama
Ngwale
Liwale
Njinjo
Zinga
Nyamtumbo
Songea
Mbinga
Manda
Chilumba
Karonga
Nkhata Bay
Mzuzu
Rumphi
Mzimba
Nkhotakota
Salima
LILONGWE
Dedza
Mangochi
Njombe
Mdandu
Mbeya
Chimala
Chunya
Kipembawe
Rungwa
Iringa
Ulete
Dabaga
Ifakara
Mahenge
Kidatu
Kilosa
Morogoro
Kisangire
Kanga
Dodoma
Meia Meia
Kibaya
Kondoa
Mgori
Singida
Kinyangiri
Suna
Ikungu
Manyoni
Mkomazi
Korogwe
35°
37° 30´
7° 30´
10°
12° 30´
40°
SCALE 1:3 000 000
1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES
0
100
200 km
0
50
100 miles
PROJECTION: Lambert Azimuthal

121

114



SCALE 1:3 000 000

1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES

0 100 200 km

0 50 100 miles

PROJECTION: Lambert Azimuthal

This map shows the soils of southern Angola, north-western Botswana, northern Namibia and south-western Zambia. The dominant geographical features of the region include the Namib and Kalahari Deserts and, contrastingly, the ecologically important wetlands of the Okavango and Zambezi Rivers. Topographically, most of the area shown on the map is controlled by the Kalahari Basin, a large lowland area occupying most of Botswana and large parts of Angola, Namibia, South Africa, Zambia and Zimbabwe. The semi-arid Kalahari Desert occupies the centre of the basin. The mountains on the western rim rise to over 2 000 m before dropping to a narrow coastal plain, dominated by the very arid Namib Desert.

Lying on the southern edge of the tropical zone gives the climate of the region an increasing seasonality. Generally from north to south, precipitation decreases while temperatures increase. The coastal plain is cooled by the ocean but is very dry (less than 50 mm of rainfall annually). Inland, the land rises sharply before descending in elevation towards the Kalahari (Windhoek in Namibia has an elevation of 1 700 m above sea level). The Kalahari has a large daily temperature range of more than 30°C in the summer dropping to less than 10°C in the winter. Humidity across the area is low and rainfall increases from about 250 mm in the south to about 600 mm in the north. However, rainfall is highly variable and droughts are common.

Vegetation grades from deciduous forests in the north-central part of the map to shrubby savannah and desert in the south. Numerous reed beds and marshes occur along river valleys, especially the Okavango and the tributaries of the Zambezi.

It is clear that climate, and particularly aridity, is the dominant factor on this map. The Namib extends for more than 2 000 km along the Atlantic coast of Angola, Namibia and South Africa, but is only 200 km wide at its greatest extent. Geologically, the map covers the divide between the plateaus of the Congo Craton to the north and the Kaapvaal Craton of southern Africa. A band of very old (pre-Cambrian) rocks gives rise to a zone of gravelly Leptosols and bare rocks running parallel to the coast. Seaward, extensive lime- and gypsum-rich soils are often overlain by wind-blown sand seas (Arenosols). Some dunes reach a height of 300 m and are over 30 km long. The area around Torra Bay is the infamous Skeleton Coast, known for its extreme aridity and numerous shipwrecks. The large extent of saline soils (Solonchaks, Solonetz) on the Angolan/Namibian boarder denotes the ephemeral hydrology of the Etosha depression.

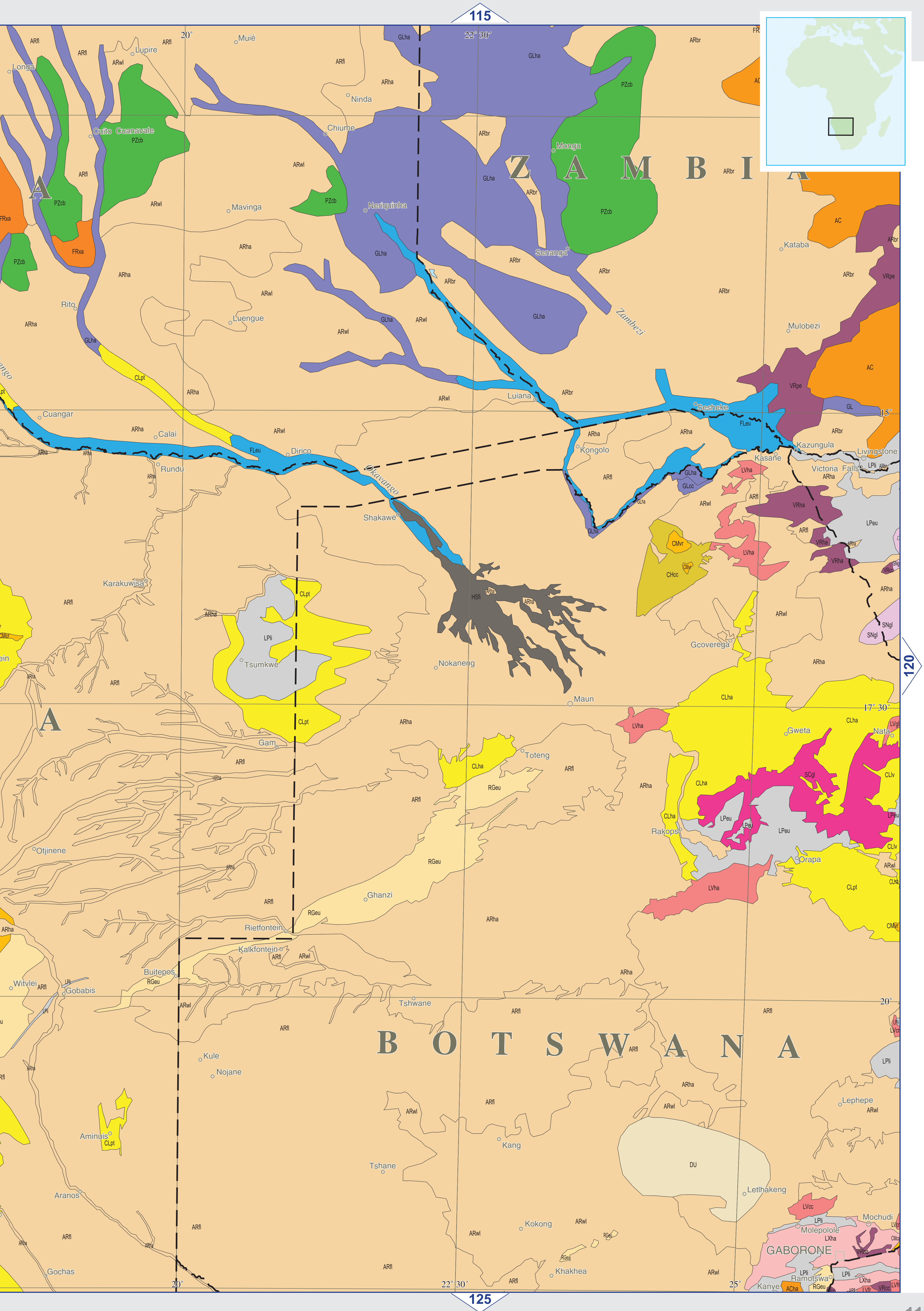
Towards the centre of the map, dry and hot conditions give rise to an assemblage of Solonchaks, Calcisols, Regosols and extensive Arenosols. Fluvisols and Gleysols denote the floodplain of the Okavango River and the notable tributaries of the Zambezi. Many channels are dry for large parts of the year. A significant feature on the map is the large area of peat accumulation (Histosols) that reflects seasonal flooding across the vast, flat terrain of the inland delta of the Okavango. To the southeast, the region of saline- and calcium carbonate-rich soils denotes the Makgadikgadi pans, a broad inland basin that was once occupied by an enormous lake that dried up several thousand years ago when the climate of the region became much drier. The large expanse of Gleysols in the top-right corner of the map is the Zambezi Floodplain, an internationally recognised wetland site.

From an African perspective, this map contains a rather rare appearance of Podzols, which have developed in the predominantly sandy parent material of southern Angola and Zambia. Here, slightly higher precipitation levels compared to the rest of the map give rise to more wooded vegetation, and leaching can lead to the development of Podzols in freely draining conditions.

While much of the soils on this map sheet are rocky or sandy, a lack of water is the primary constraint on agriculture. Where the soils are cultivated, overuse has led to compacted soils and serious erosion.

124

115



Z A M B I A
B O T S W A N A
A
A
20°
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Muié
Lupire
Longa
Ninda
Chiume
Cuito Cuanavale
Mongu
Neriquinha
Mavinga
Senanga
Kataba
Luengue
Rito
Mulobezi
Zambezi
Luiana
Sesheke
Cuangar
Calai
Dirico
Rundu
Kongolo
Kasane
Kazungula
Livingstone
Victoria Falls
Okavango
Shakawe
Karakuwisa
Tsumkwe
Nokaneng
Gcoverega
Maun
Gam
Toteng
Gweta
Nata
Rakops
Orapa
Otjinene
Ghanzi
Rietfontein
Kalkfontein
Buitepos
Witvlei
Gobabis
Tshwane
Kule
Nojane
Aminuis
Kang
Lephepe
Letlhakeng
Tshane
Aranos
Kokong
Mochudi
Molepolole
GABORONE
Ramotswa
Kanye
Khakhea
Gochas
ARfl
ARwl
ARha
ARbr
GLha
PZcb
FRxa
CLpt
FLeu
AC
VRpe
GL
LPli
LPeu
LVha
VRha
CHcc
CMvr
HSfi
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CLha
RGeu
SCgl
CLlv
DU
LVcc
LXha
ACha

120

125

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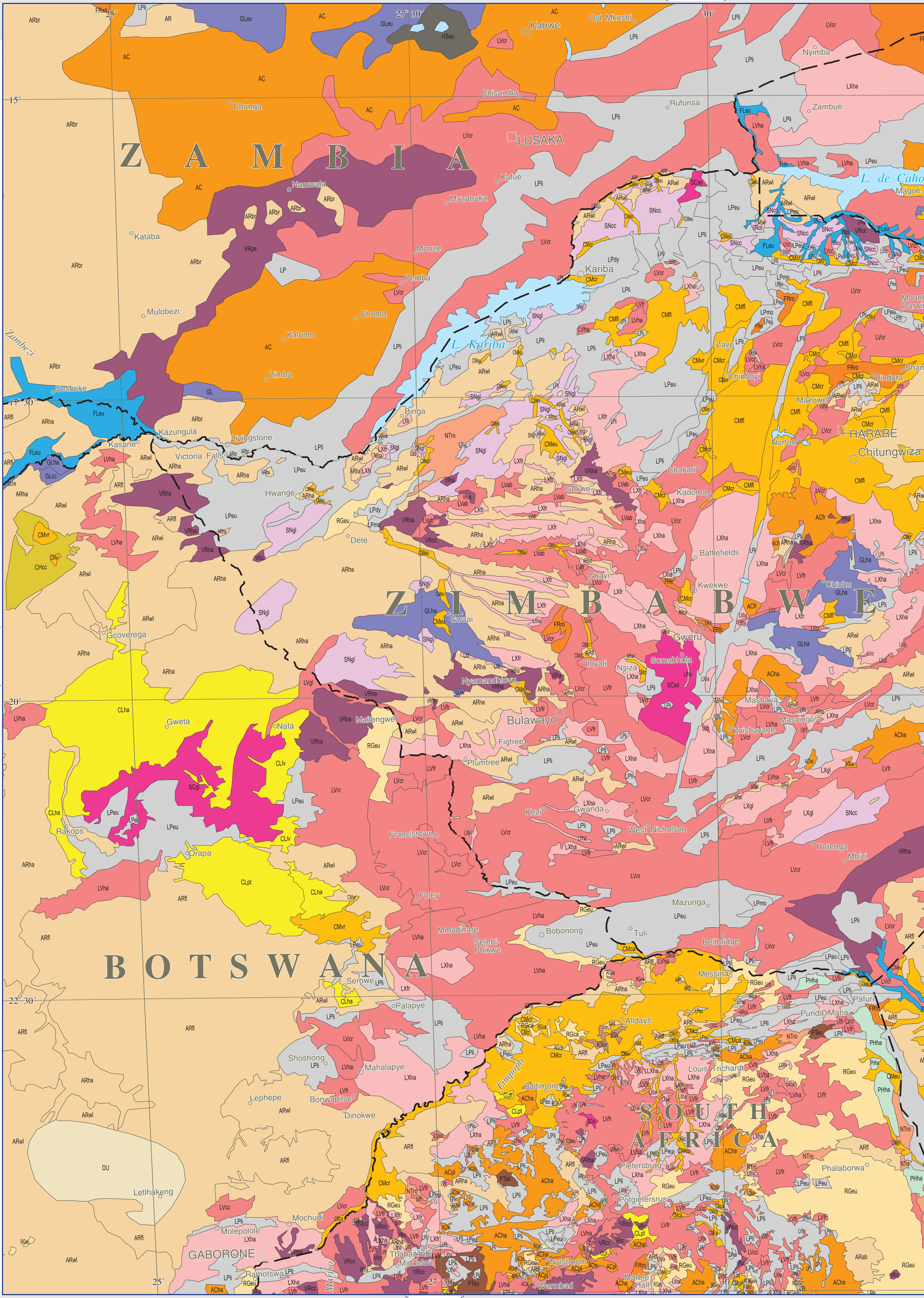
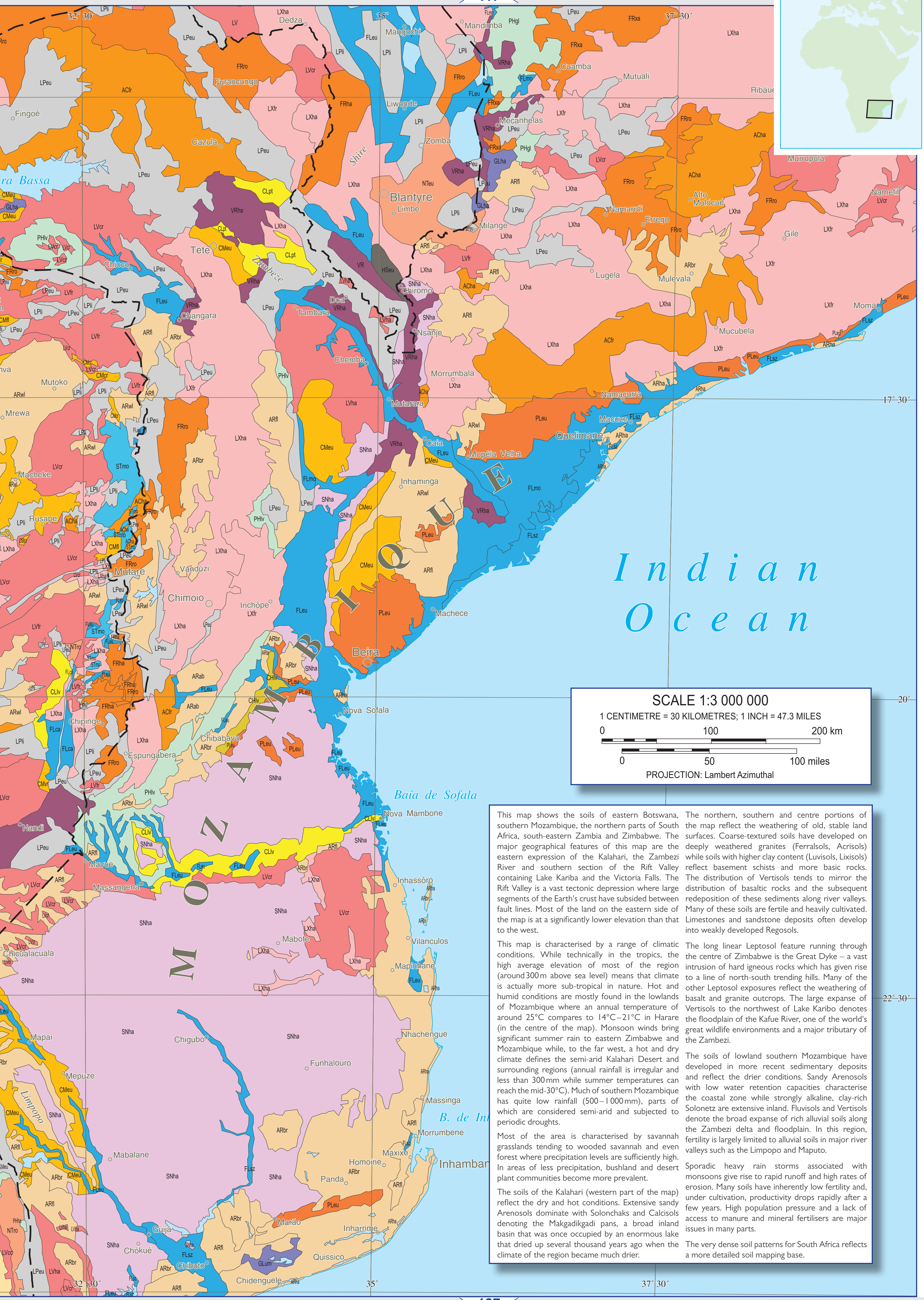

ZAMBIA
ZIMBABWE
BOTSWANA
SOUTH AFRICA
LUSAKA
HARARE
GABORONE
Kabwe
Old Mkushi
Chisamba
Rufunsa
Chunga
Namwala
Kafue
Mazabuka
Kataba
Monze
Pemba
Mulobezi
Choma
Kalomo
Zimba
Sesheke
Kasane
Kazungula
Livingstone
Victoria Falls
Hwange
Dete
Binga
Kariba
L. Kariba
Zambezi
L. de Cahora Bassa
Mágoé
Nyimba
Zambuè
Zave
Chinhoyi
Bindura
Mazowe
Norton
Chitungwiza
Chakari
Kadoma
Gokwe
Battlefields
Kwekwe
Nkayi
Gwaai
Gweru
Chivhu
Inyati
Nsiza
Somabhula
Shangani
Nyamandhlovu
Bulawayo
Figtree
Plumtree
Mashava
Masvingo
Zvishavane
Kezi
Gwanda
West Nicholson
Rutenga
Mbizi
Francistown
Foley
Mmadinare
Selebi-Phikwe
Bobonong
Tuli
Mazunga
Beitbridge
Messina
Pafuri
Punda Maria
Alldays
Louis Trichardt
Baltimore
Limpopo
Pietersburg
Potgietersrus
Phalaborwa
Nylstroom
Warmbad
Marble Hall
Thabazimbi
Middelwit
Mochudi
Molepolole
Ramotswa
Marico
Letlhakeng
Lephepe
Bonwapitse
Dinokwe
Shoshong
Mahalapye
Palapye
Serowe
Orapa
Rakops
Gweta
Nata
Maitengwe
Gcoverega
Mount Darwin
15°
17° 30'
20°
22° 30'
25°
27° 30'
30°

126

117



This map shows the soils of eastern Botswana, southern Mozambique, the northern parts of South Africa, south-eastern Zambia and Zimbabwe. The major geographical features of the region are the eastern expression of the Kalahari, the Zambezi River and southern section of the Rift Valley containing Lake Kariba and the Victoria Falls. The Rift Valley is a vast tectonic depression where large segments of the Earth's crust have subsided between fault lines. Most of the land on the eastern side of the map is at a significantly lower elevation than that to the west.

This map is characterised by a range of climatic conditions. While technically in the tropics, the high average elevation of most of the region (around 300 m above sea level) means that climate is actually more sub-tropical in nature. Hot and humid conditions are mostly found in the lowlands of Mozambique where an annual temperature of around 25°C compares to 14°C–21°C in Harare (in the centre of the map). Monsoon winds bring significant summer rain to eastern Zimbabwe and Mozambique while, to the far west, a hot and dry climate defines the semi-arid Kalahari Desert and surrounding regions (annual rainfall is irregular and less than 300 mm while summer temperatures can reach the mid-30°C). Much of southern Mozambique has quite low rainfall (500–1 000 mm), parts of which are considered semi-arid and subjected to periodic droughts.

Most of the area is characterised by savannah grasslands tending to wooded savannah and even forest where precipitation levels are sufficiently high. In areas of less precipitation, bushland and desert plant communities become more prevalent.

The soils of the Kalahari (western part of the map) reflect the dry and hot conditions. Extensive sandy Arenosols dominate with Solonchaks and Calcisols denoting the Makgadikgadi pans, a broad inland basin that was once occupied by an enormous lake that dried up several thousand years ago when the climate of the region became much drier.

The northern, southern and centre portions of the map reflect the weathering of old, stable land surfaces. Coarse-textured soils have developed on deeply weathered granites (Ferralsols, Acrisols) while soils with higher clay content (Luvisols, Lixisols) reflect basement schists and more basic rocks. The distribution of Vertisols tends to mirror the distribution of basaltic rocks and the subsequent redeposition of these sediments along river valleys. Many of these soils are fertile and heavily cultivated. Limestones and sandstone deposits often develop into weakly developed Regosols.

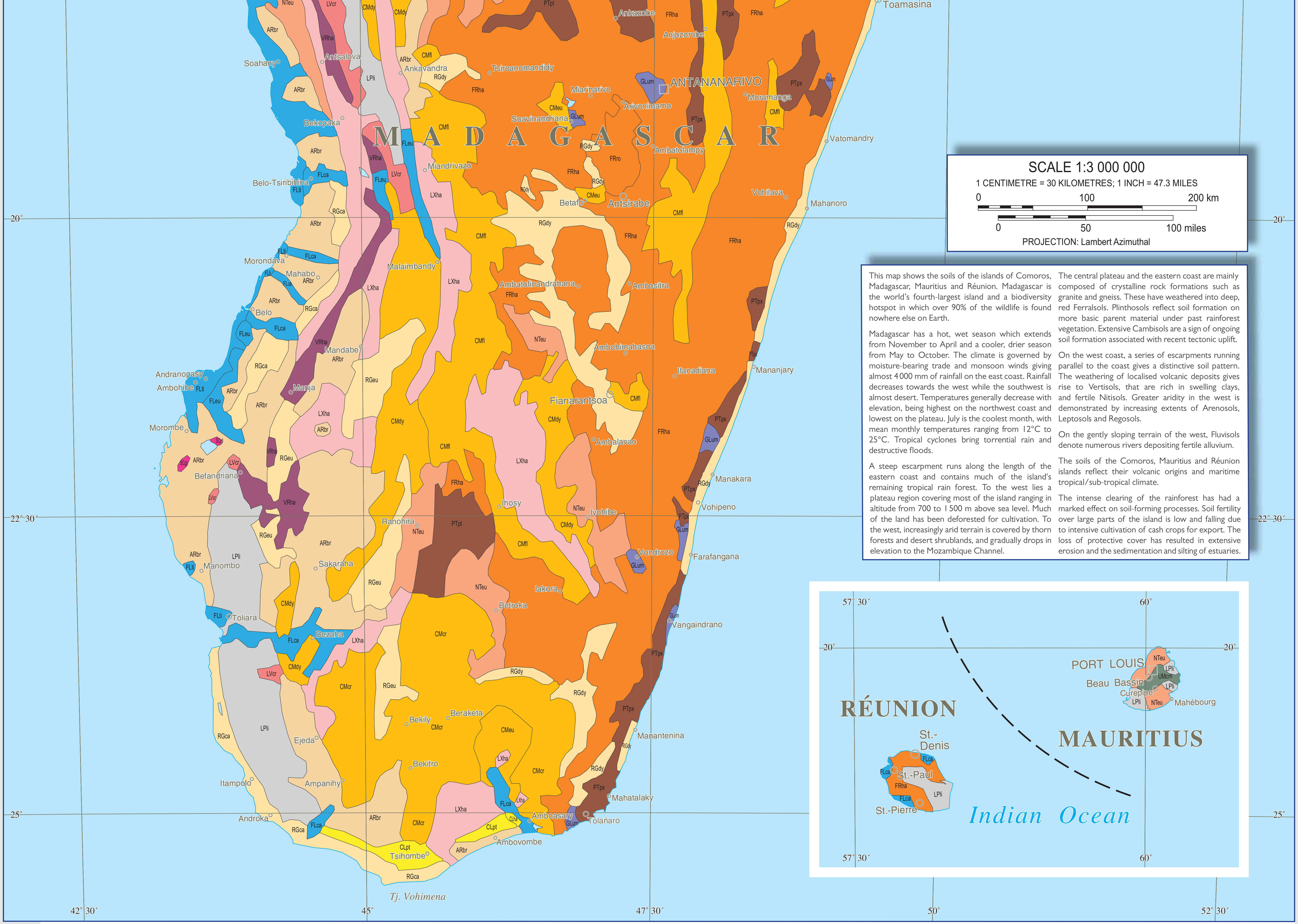
The long linear Leptosol feature running through the centre of Zimbabwe is the Great Dyke – a vast intrusion of hard igneous rocks which has given rise to a line of north-south trending hills. Many of the other Leptosol exposures reflect the weathering of basalt and granite outcrops. The large expanse of Vertisols to the northwest of Lake Karibo denotes the floodplain of the Kafue River, one of the world's great wildlife environments and a major tributary of the Zambezi.

The soils of lowland southern Mozambique have developed in more recent sedimentary deposits and reflect the drier conditions. Sandy Arenosols with low water retention capacities characterise the coastal zone while strongly alkaline, clay-rich Solonetz are extensive inland. Fluvisols and Vertisols denote the broad expanse of rich alluvial soils along the Zambezi delta and floodplain. In this region, fertility is largely limited to alluvial soils in major river valleys such as the Limpopo and Maputo.

Sporadic heavy rain storms associated with monsoons give rise to rapid runoff and high rates of erosion. Many soils have inherently low fertility and, under cultivation, productivity drops rapidly after a few years. High population pressure and a lack of access to manure and mineral fertilisers are major issues in many parts.

The very dense soil patterns for South Africa reflects a more detailed soil mapping base.

127



SCALE 1:3 000 000

1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES

0 100 200 km

0 50 100 miles

PROJECTION: Lambert Azimuthal

This map shows the soils of the islands of Comoros, Madagascar, Mauritius and Réunion. Madagascar is the world's fourth-largest island and a biodiversity hotspot in which over 90% of the wildlife is found nowhere else on Earth.

Madagascar has a hot, wet season which extends from November to April and a cooler, drier season from May to October. The climate is governed by moisture-bearing trade and monsoon winds giving almost 4 000 mm of rainfall on the east coast. Rainfall decreases towards the west while the southwest is almost desert. Temperatures generally decrease with elevation, being highest on the northwest coast and lowest on the plateau. July is the coolest month, with mean monthly temperatures ranging from 12°C to 25°C. Tropical cyclones bring torrential rain and destructive floods.

A steep escarpment runs along the length of the eastern coast and contains much of the island's remaining tropical rain forest. To the west lies a plateau region covering most of the island ranging in altitude from 700 to 1 500 m above sea level. Much of the land has been deforested for cultivation. To the west, increasingly arid terrain is covered by thorn forests and desert shrublands, and gradually drops in elevation to the Mozambique Channel.

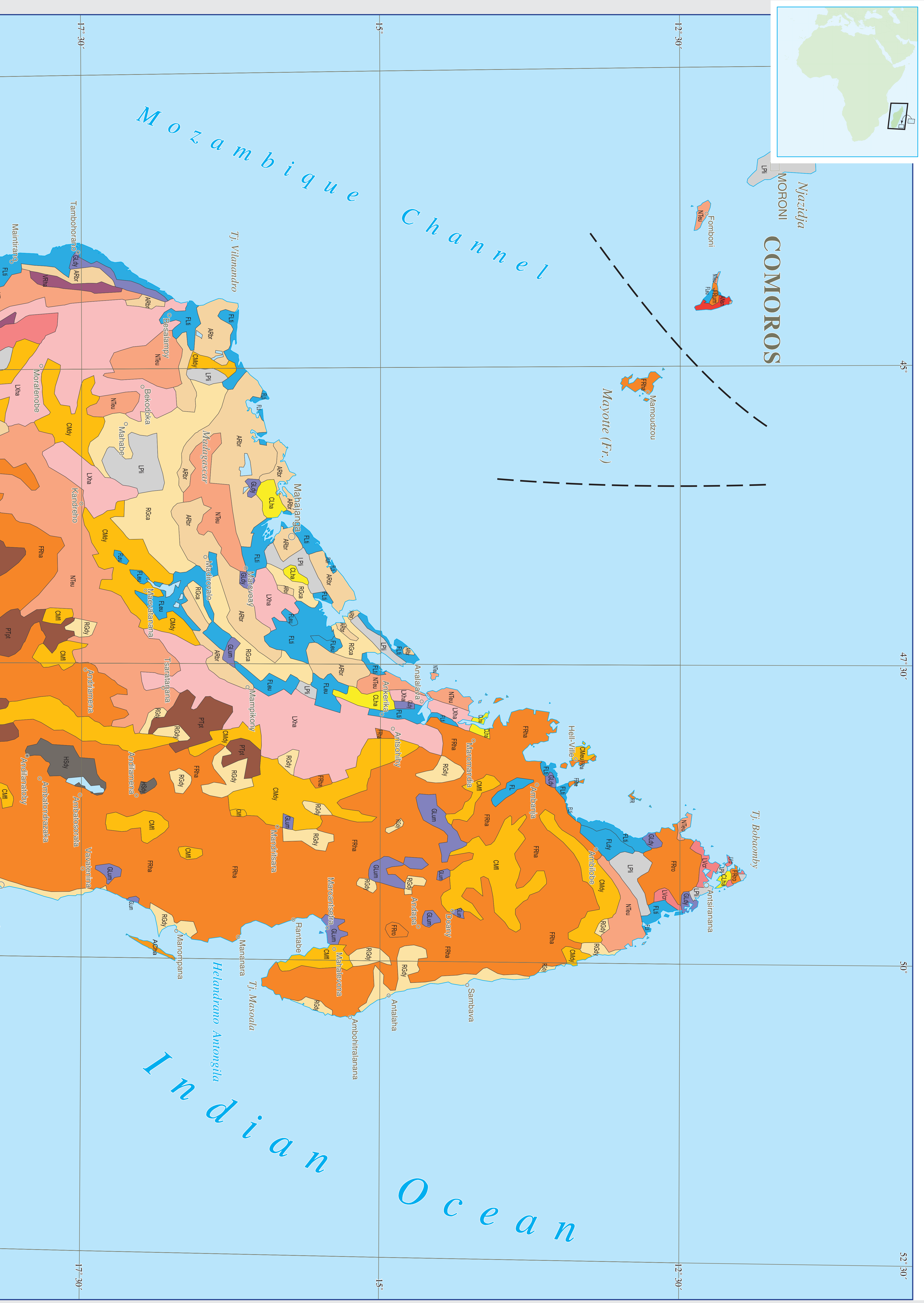
The central plateau and the eastern coast are mainly composed of crystalline rock formations such as granite and gneiss. These have weathered into deep, red Ferralsols. Plinthosols reflect soil formation on more basic parent material under past rainforest vegetation. Extensive Cambisols are a sign of ongoing soil formation associated with recent tectonic uplift.

On the west coast, a series of escarpments running parallel to the coast gives a distinctive soil pattern. The weathering of localised volcanic deposits gives rise to Vertisols, that are rich in swelling clays, and fertile Nitisols. Greater aridity in the west is demonstrated by increasing extents of Arenosols, Leptosols and Regosols.

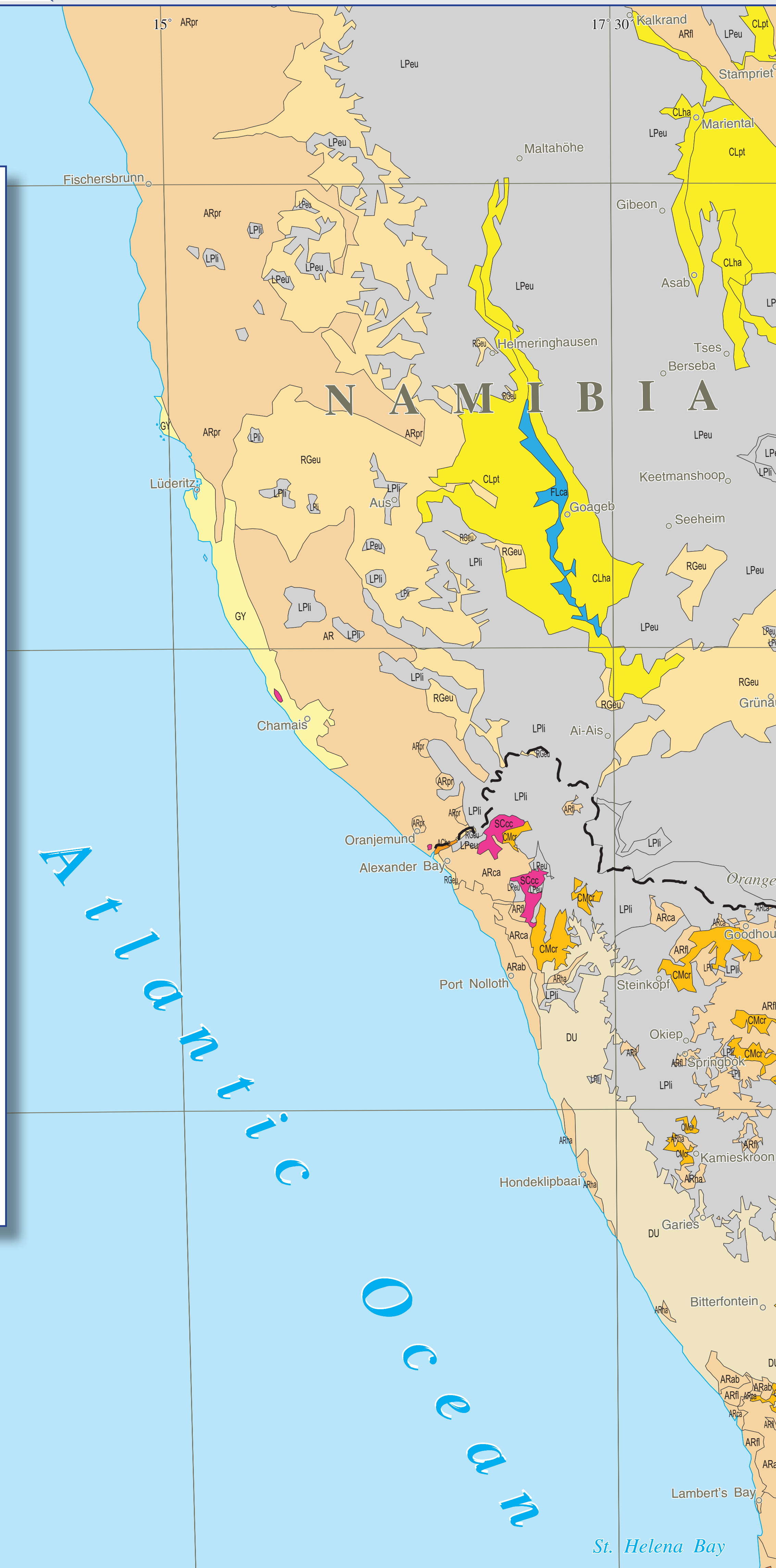
On the gently sloping terrain of the west, Fluvisols denote numerous rivers depositing fertile alluvium.

The soils of the Comoros, Mauritius and Réunion islands reflect their volcanic origins and maritime tropical/sub-tropical climate.

The intense clearing of the rainforest has had a marked effect on soil-forming processes. Soil fertility over large parts of the island is low and falling due to intensive cultivation of cash crops for export. The loss of protective cover has resulted in extensive erosion and the sedimentation and silting of estuaries.

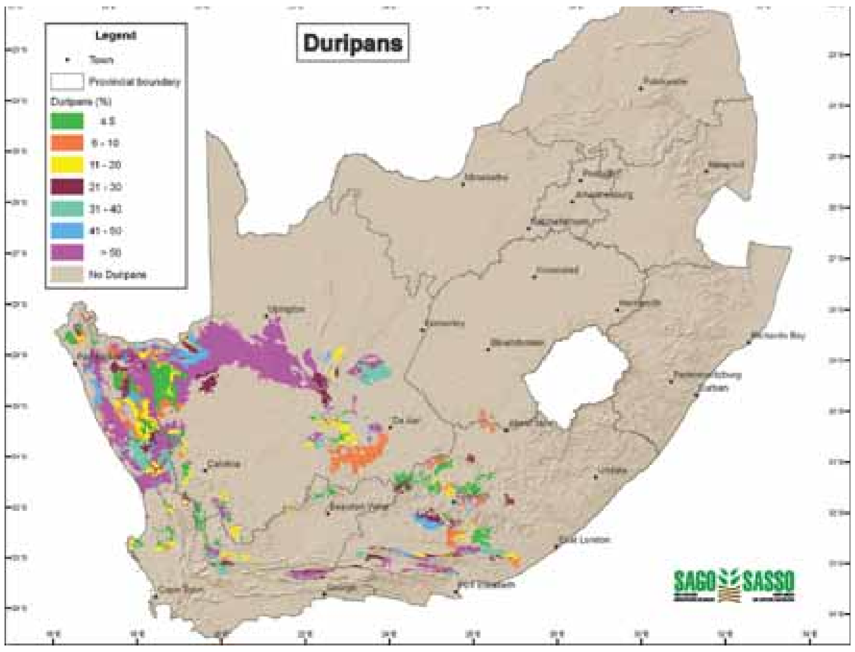


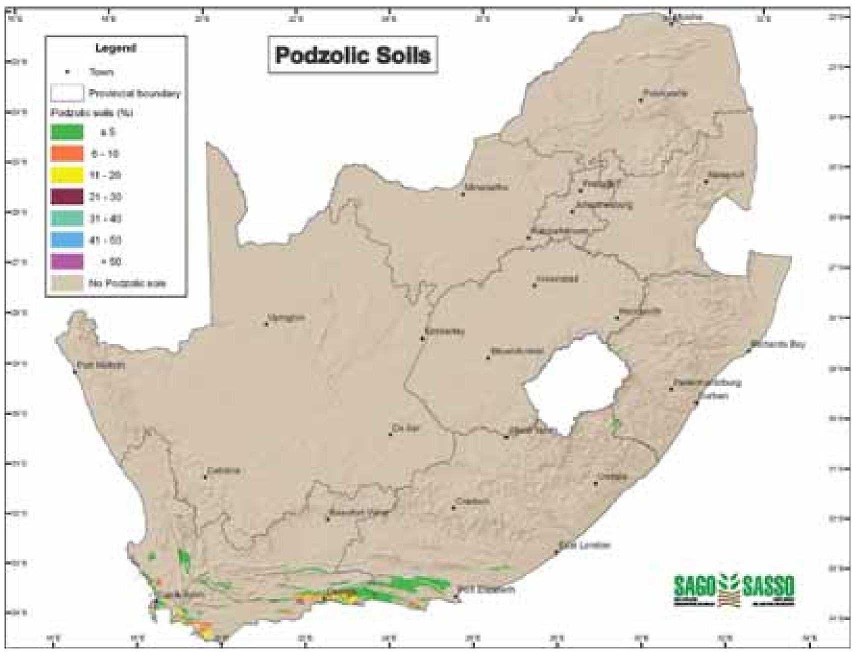
Mozambique Channel
Indian Ocean
COMOROS
MORONI
Njazidja
Fomboni
Mayotte (Fr.)
Mamoudzou
Tj. Vilanandro
Tambohorano
Maintirano
Besalampy
Morafenobe
Bekodoka
Mahabe
Kandreho
Madagascar
Mahajanga
Marovoay
Madirovalo
Maevatanana
Tsaratanana
Mampikony
Andriamena
Antsohihy
Analalava
Ankerika
Hell-Ville
Maromandia
Ambanja
Ambilobe
Antsiranana
Tj. Bobaomby
Andilamena
Ambatondrazaka
Amparafaravola
Ambatosoratra
Vavatenina
Mandritsara
Marotandrano
Andapa
Doany
Rantabe
Mananara
Manompana
Maroantsetra
Mahalevona
Antalaha
Sambava
Ambohitralanana
Tj. Masoala
Helandrano Antongila



Podzolic and silicic soils of South Africa

Compared with the rest of the continent, South Africa contains significant amounts of podzolic soils (highly leached, low in lime with subsurface accumulations of iron and organic matter) and soils that are characterised by an accretion of silica (see pages 58-59). In most cases, they do not appear on small scale maps as they are often not the dominant soil type. For this reason, the distribution maps of these two soils are provided in addition to the usual maps. [66a]





SCALE 1:3 000 000

1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES

0 100 200 km

0 50 100 miles

PROJECTION: Lambert Azimuthal

This map shows the soils of southern Botswana, southern Namibia and the western half of South Africa. The dominant geographical features of the region include the Namib and Kalahari Deserts and, contrastingly, the high plateau lands of South Africa. Topographically, the land in the northern part of the map is dominated by the Kalahari Basin, a large, semi-arid lowland area occupying most of Botswana, while to the south, the rocks of the geologically stable Karoo Basin and Kaapvaal Craton cover most of South Africa.

While the climate of the region is greatly influenced by the surrounding oceans, a subtropical high-pressure belt of descending air produces stable atmospheric conditions over most of the area giving a generally dry climate while temperatures are moderated by the fairly high elevation of much of the terrain. The west coast is cooled by the cold northward-flowing Benguela Current which also contributes to the dryness and stability of the atmosphere over western regions. Most of the area shown on the map is regarded as arid with highly variable precipitation ranging from less than 50 mm to 600 mm annually. Alexander Bay (where the Namibia-South Africa border meets the west coast) receives less than 50 mm of rain annually. Temperatures are strongly determined by elevation and distance from the sea. Summers are generally warm to hot while winters are mostly cool to cold, with higher elevations having lower temperatures.

Vegetation cover increases from north to south and west to east. Grassland savannah adjacent to the Kalahari becomes more woody to the south as rainfall increases. Winter rainfall and coastal fogs in the semi-arid southern and south-western parts of South Africa support the unique floristic diversity of the Karoo and Fynbos biomes.

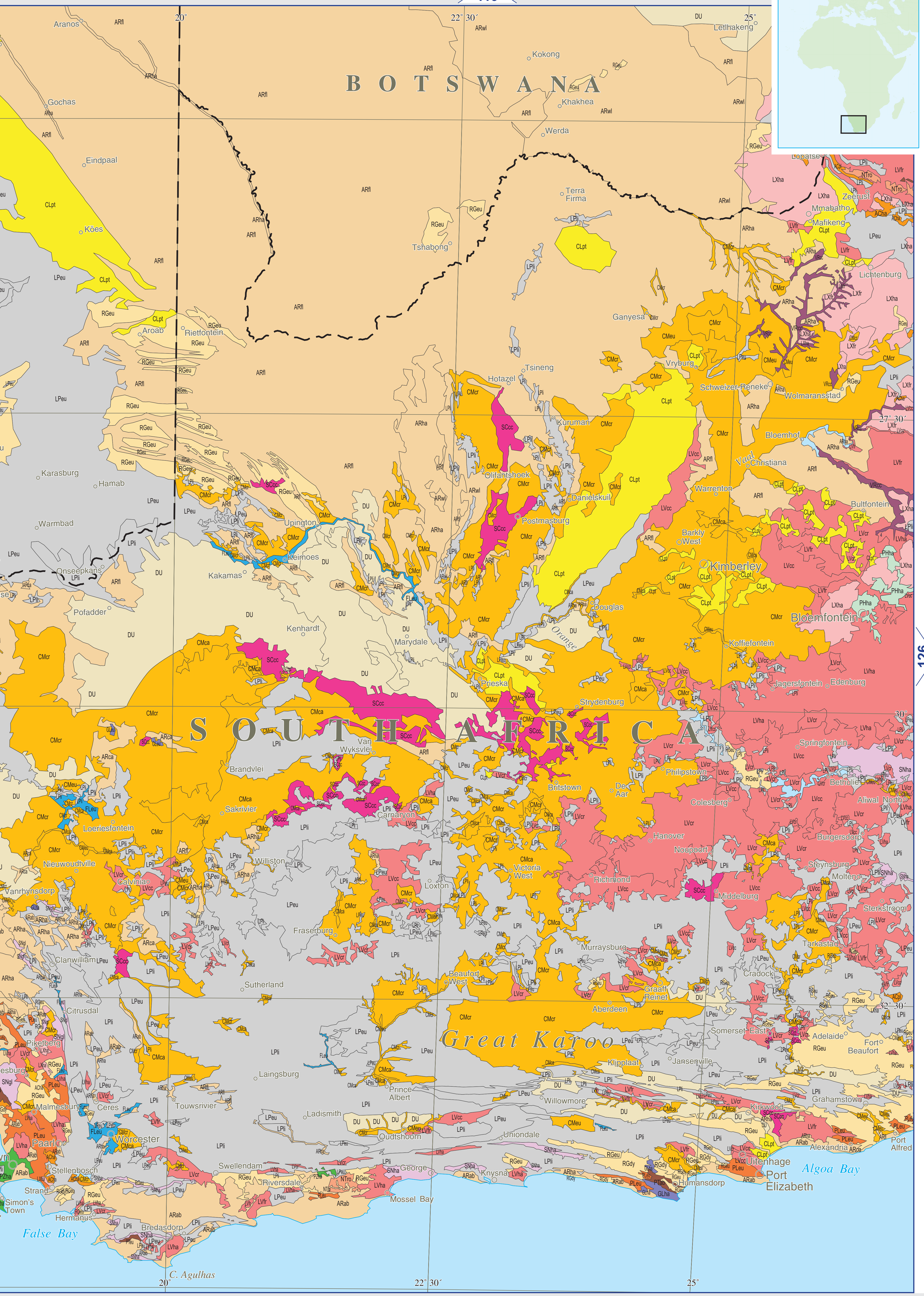
It is clear that climate, and particularly aridity, is a dominant soil-forming factor on this map. Low soil organic matter is characteristic of most of the region. Both the Namib on the Atlantic Coast and the inland Kalahari Deserts are characterised by extensive sandy Arenosols and separated by a zone of gravelly Leptosols and bare rocks running parallel to the coast. Lime-rich Calcisols and Solonchaks reflect old evaporative surfaces, salt pans and depressions in a generally flat landscape.

Soils on the higher plateau of South Africa reflect the weathering of ancient crystalline rocks. Soils are generally weakly developed sandy Cambisols or shallow Leptosols. Calcisols and Solonchaks denote the accumulation of calcium carbonates and other salts under dry conditions. Soils with a horizon cemented by silica are known as Durisols. Towards the east, changes in the underlying lithology to sedimentary rocks (associated with intrusive igneous rocks) and increased precipitation give rise to clay-rich Luvisols under extensive grasslands. Lixisols denote soil formation on strongly weathered but less acidic materials.

Between the sea and the Great Escarpment a more humid climate has led to the formation of a mosaic of sandy (Arenosols, Podzols) and sandy loam (Planosols) soils intermixed with heavier Luvisols, Gleysols and Solonetz.

The very dense soil pattern for South Africa reflects a more detailed soil mapping base. Such a level of information should be a goal for other African countries (see also Plates 17, 21 and 24).

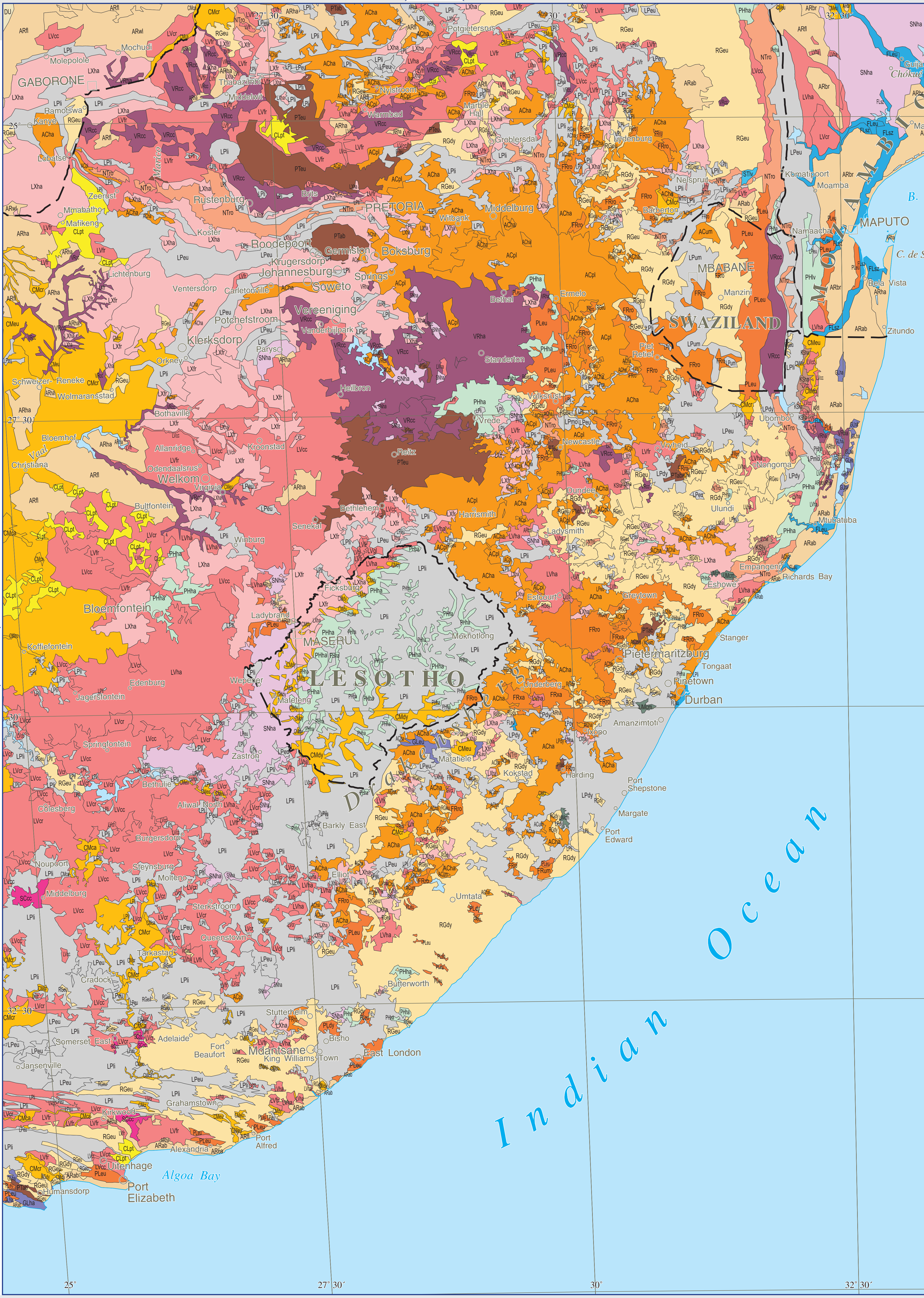
119

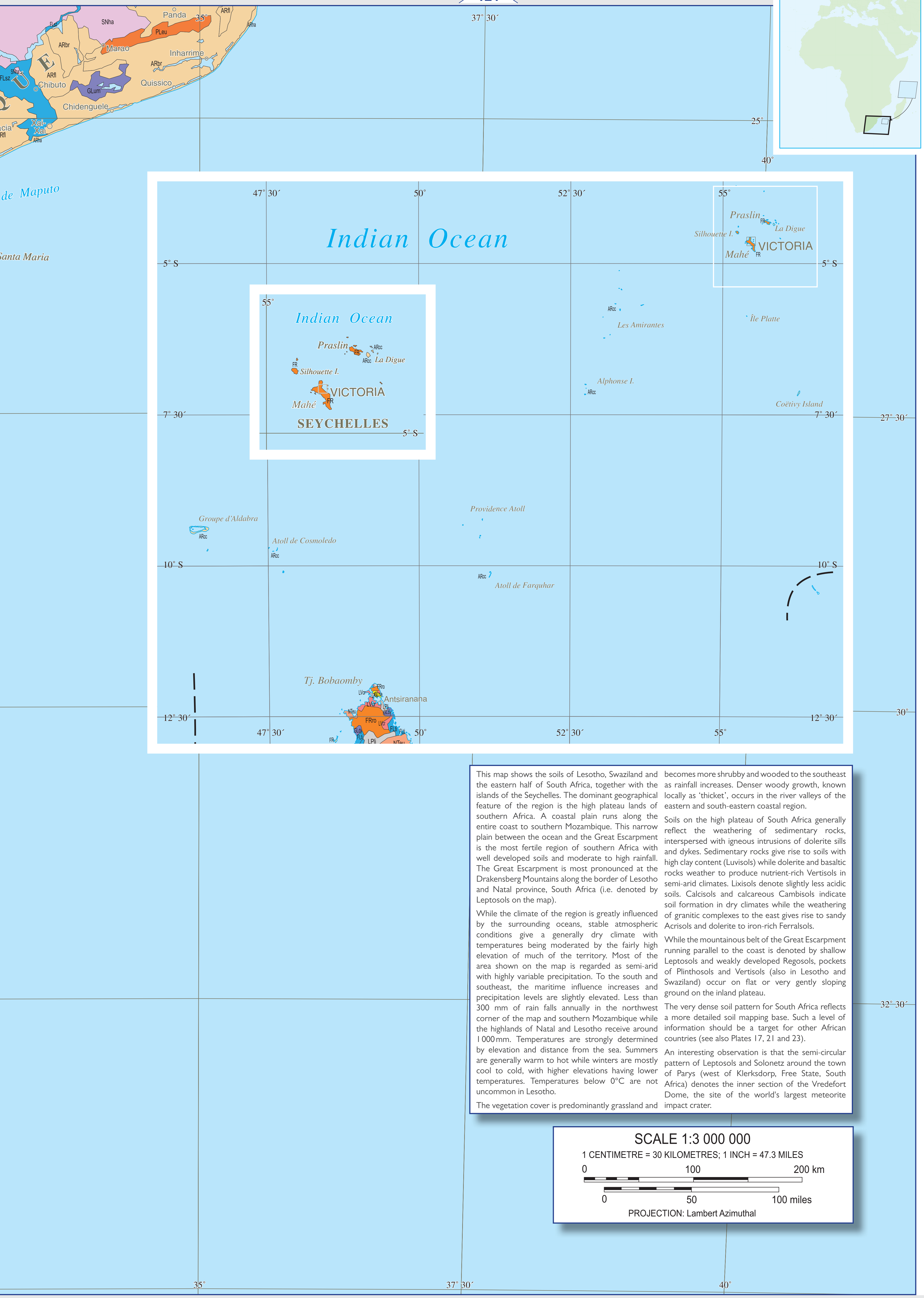

BOTSWANA
SOUTH AFRICA
Great Karoo
Aranos
Gochas
Eindpaal
Köes
Aroab
Rietfontein
Karasburg
Hamab
Warmbad
Onseepkans
Pofadder
Kakamas
Keimoes
Upington
Kenhardt
Marydale
Kokong
Khakhea
Werda
Terra Firma
Tshabong
Ganyesa
Tsineng
Hotazel
Kuruman
Olifantshoek
Danielskuil
Postmasburg
Vryburg
Schweizer-Reneke
Wolmaransstad
Letlhakeng
Lobatse
Zeerust
Mmabatho
Mafikeng
Lichtenburg
Bloemhof
Christiana
Warrenton
Barkly West
Kimberley
Bultfontein
Douglas
Bloemfontein
Koffiefontein
Jagersfontein
Edenburg
Prieska
Strydenburg
Springfontein
Philipstown
Bethulie
Aliwal North
Colesberg
Britstown
De Aar
Hanover
Noupoort
Burgersdorp
Steynsburg
Molteno
Middelburg
Sterkstroom
Tarkastad
Richmond
Vaal
Orange
Van Wyksvlei
Brandvlei
Sakrivier
Carnarvon
Loeriesfontein
Nieuwoudtville
Calvinia
Williston
Loxton
Victoria West
Vanrhynsdorp
Fraserburg
Clanwilliam
Sutherland
Murraysburg
Beaufort West
Graaff Reinet
Aberdeen
Cradock
Citrusdal
Piketberg
Somerset East
Adelaide
Fort Beaufort
Jansenville
Klipplaat
Laingsburg
Prince Albert
Willowmore
Kirkwood
Grahamstown
Touwsrivier
Ceres
Malmesbury
Paarl
Worcester
Ladismith
Oudtshoorn
Uniondale
Stellenbosch
Swellendam
Riversdale
George
Knysna
Mossel Bay
Humansdorp
Uitenhage
Port Elizabeth
Algoa Bay
Alexandria
Port Alfred
Strand
Simon's Town
Hermanus
False Bay
Bredasdorp
C. Agulhas
20°
22° 30′
25°
27° 30′
30°
32° 30′

126

120

125


GABORONE
Mochudi
Molepolole
Kanye
Ramotswa
Lobatse
Zeerust
Mmabatho
Mafikeng
Lichtenburg
Ventersdorp
Thabazimbi
Middelwit
Nylstroom
Warmbad
Potgietersrus
Marble Hall
Groblersdal
Lydenburg
Rustenburg
Brits
PRETORIA
Witbank
Middelburg
Nelspruit
Barberton
Komatipoort
Moamba
MAPUTO
Namaacha
MBABANE
Manzini
SWAZILAND
Bela Vista
Zitundo
Koster
Roodepoort
Germiston
Boksburg
Krugersdorp
Johannesburg
Springs
Soweto
Carletonville
Vereeniging
Vanderbijlpark
Potchefstroom
Klerksdorp
Parys
Orkney
Bethal
Ermelo
Standerton
Piet Retief
Heilbron
Volksrust
Vrede
Newcastle
Vryheid
Nongoma
Ubombo
Ulundi
Dundee
Mtubatuba
Empangeni
Richards Bay
Eshowe
Schweizer-Reneke
Wolmaransstad
Bothaville
Bloemhof
Christiana
Vaal
Allanridge
Kroonstad
Odendaalsrus
Welkom
Virginia
Reitz
Bethlehem
Harrismith
Ladysmith
Senekal
Bultfontein
Winburg
Ficksburg
Estcourt
Greytown
Stanger
Bloemfontein
Ladybrand
MASERU
LESOTHO
Mokhotlong
Pietermaritzburg
Tongaat
Pinetown
Durban
Amanzimtoti
Ixopo
Underberg
Drakensberg
Koffiefontein
Edenburg
Jagersfontein
Wepener
Mafeteng
Zastron
Matatiele
Kokstad
Harding
Port Shepstone
Margate
Port Edward
Springfontein
Bethulie
Aliwal North
Colesberg
Burgersdorp
Barkly East
Noupoort
Steynsburg
Molteno
Middelburg
Elliot
Umtata
Sterkstroom
Queenstown
Tarkastad
Cradock
Butterworth
Stutterheim
Bisho
Mdantsane
King Williams Town
East London
Somerset East
Adelaide
Fort Beaufort
Jansenville
Grahamstown
Kirkwood
Port Alfred
Alexandria
Uitenhage
Algoa Bay
Humansdorp
Port Elizabeth
Indian Ocean
MOÇAMBIQUE
Chókwè
C. de S
25°
27° 30′
30°
32° 30′



This map shows the soils of Lesotho, Swaziland and the eastern half of South Africa, together with the islands of the Seychelles. The dominant geographical feature of the region is the high plateau lands of southern Africa. A coastal plain runs along the entire coast to southern Mozambique. This narrow plain between the ocean and the Great Escarpment is the most fertile region of southern Africa with well developed soils and moderate to high rainfall. The Great Escarpment is most pronounced at the Drakensberg Mountains along the border of Lesotho and Natal province, South Africa (i.e. denoted by Leptosols on the map).

While the climate of the region is greatly influenced by the surrounding oceans, stable atmospheric conditions give a generally dry climate with temperatures being moderated by the fairly high elevation of much of the territory. Most of the area shown on the map is regarded as semi-arid with highly variable precipitation. To the south and southeast, the maritime influence increases and precipitation levels are slightly elevated. Less than 300 mm of rain falls annually in the northwest corner of the map and southern Mozambique while the highlands of Natal and Lesotho receive around 1 000 mm. Temperatures are strongly determined by elevation and distance from the sea. Summers are generally warm to hot while winters are mostly cool to cold, with higher elevations having lower temperatures. Temperatures below 0°C are not uncommon in Lesotho.

The vegetation cover is predominantly grassland and becomes more shrubby and wooded to the southeast as rainfall increases. Denser woody growth, known locally as 'thicket', occurs in the river valleys of the eastern and south-eastern coastal region.

Soils on the high plateau of South Africa generally reflect the weathering of sedimentary rocks, interspersed with igneous intrusions of dolerite sills and dykes. Sedimentary rocks give rise to soils with high clay content (Luvisols) while dolerite and basaltic rocks weather to produce nutrient-rich Vertisols in semi-arid climates. Lixisols denote slightly less acidic soils. Calcisols and calcareous Cambisols indicate soil formation in dry climates while the weathering of granitic complexes to the east gives rise to sandy Acrisols and dolerite to iron-rich Ferralsols.

While the mountainous belt of the Great Escarpment running parallel to the coast is denoted by shallow Leptosols and weakly developed Regosols, pockets of Plinthosols and Vertisols (also in Lesotho and Swaziland) occur on flat or very gently sloping ground on the inland plateau.

The very dense soil pattern for South Africa reflects a more detailed soil mapping base. Such a level of information should be a target for other African countries (see also Plates 17, 21 and 23).

An interesting observation is that the semi-circular pattern of Leptosols and Solonetz around the town of Parys (west of Klerksdorp, Free State, South Africa) denotes the inner section of the Vredefort Dome, the site of the world's largest meteorite impact crater.

SCALE 1:3 000 000

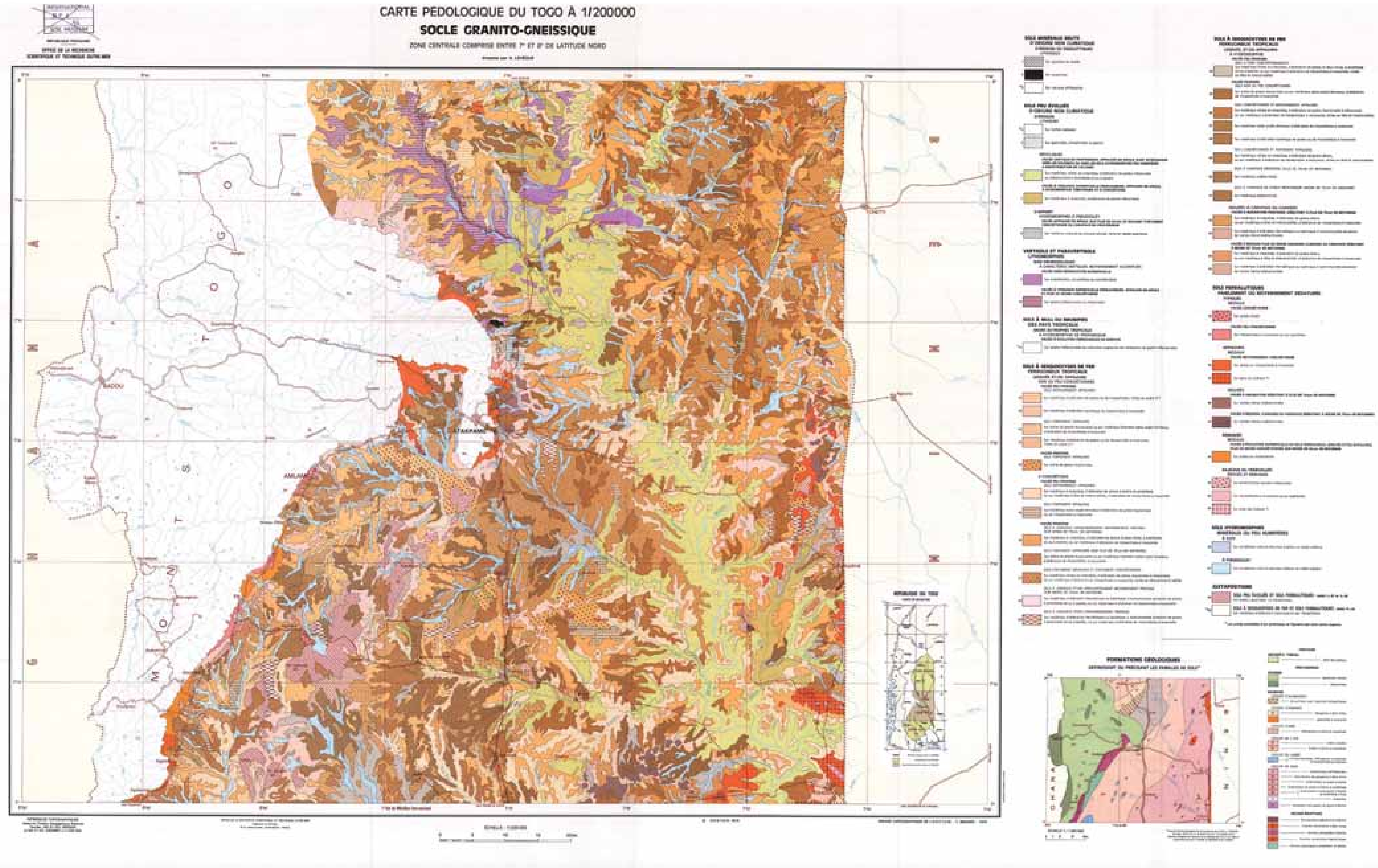
1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES

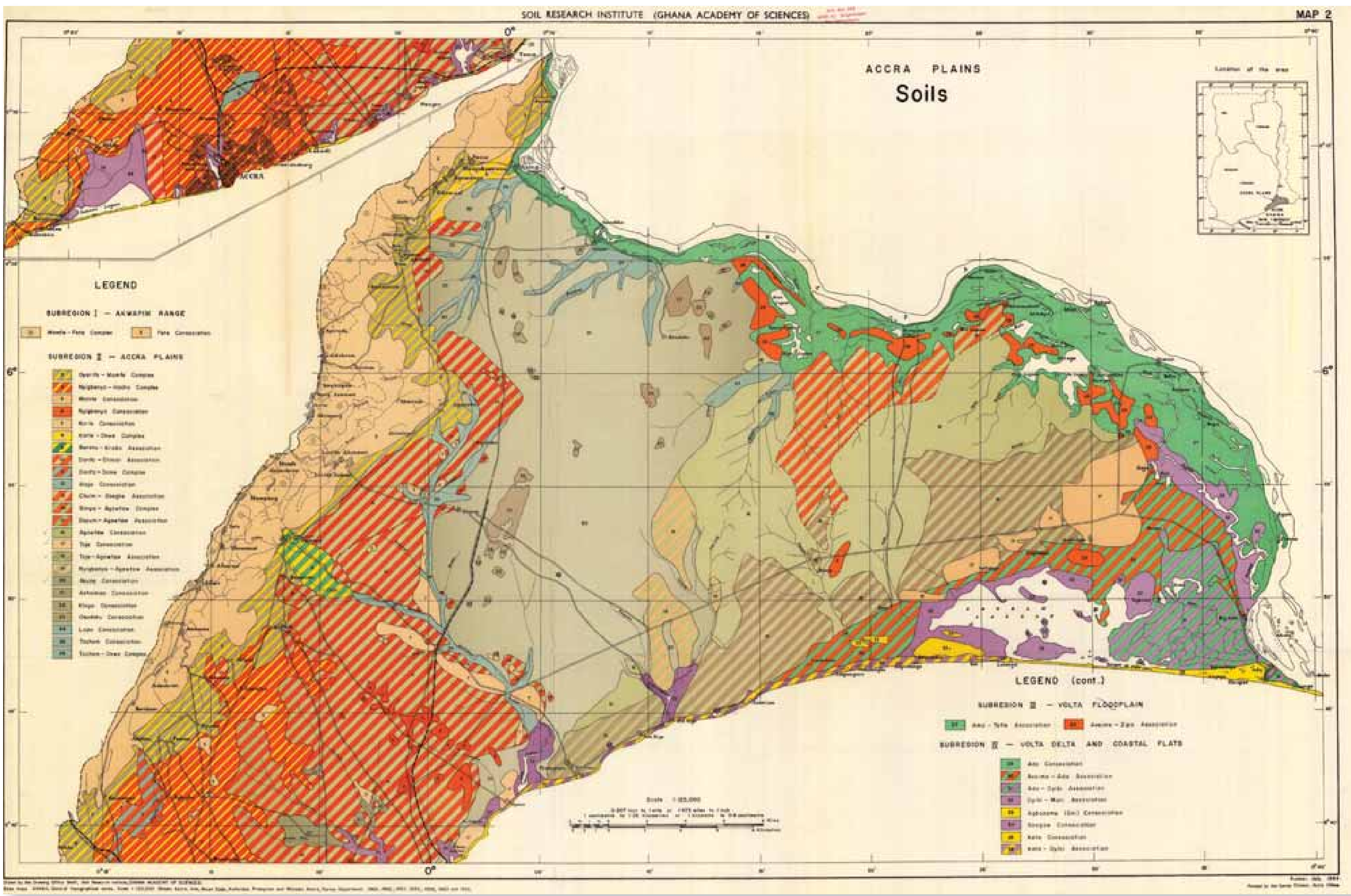
0 100 200 km

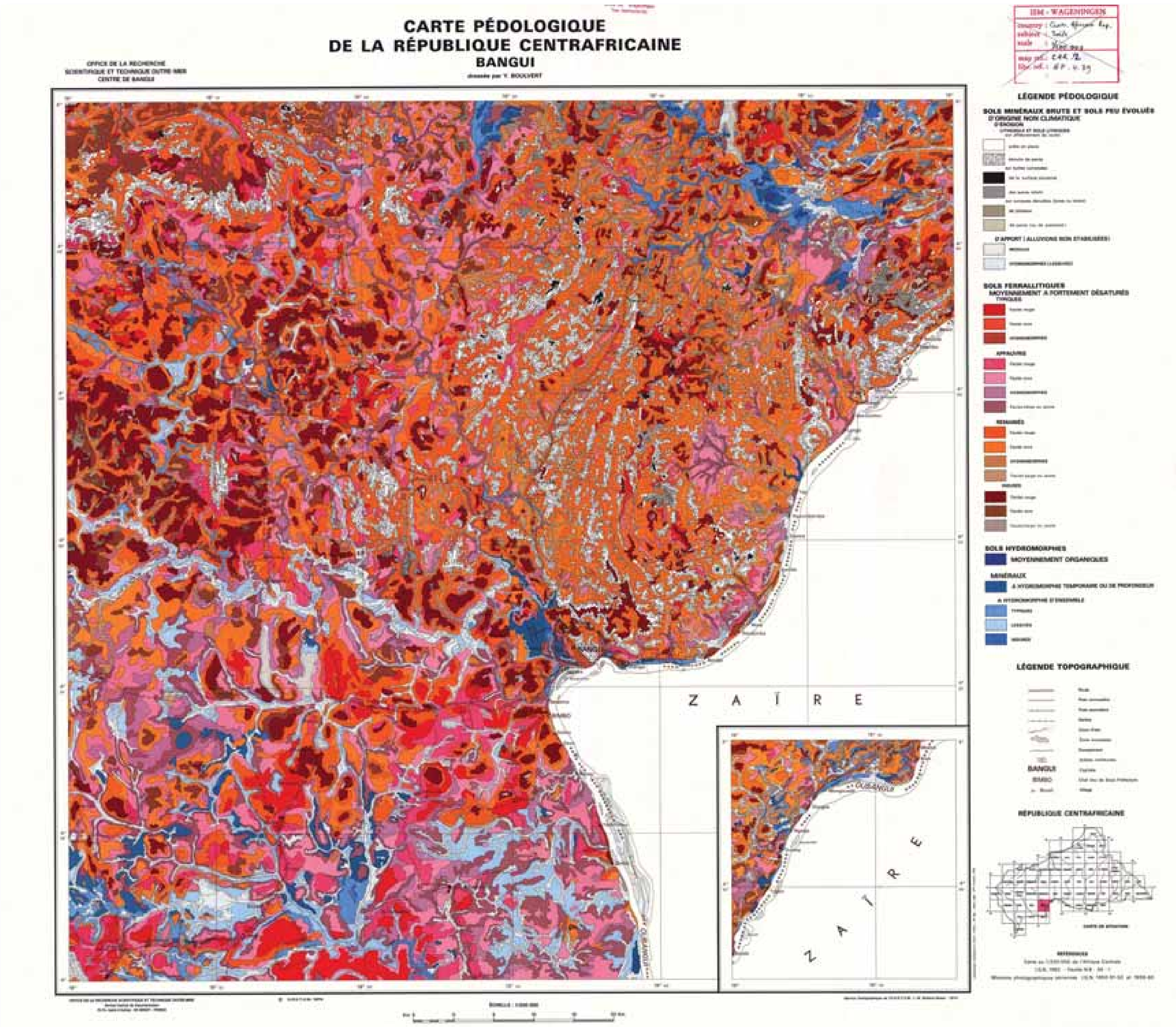
0 50 100 miles

PROJECTION: Lambert Azimuthal

Examples of medium-scale soil maps







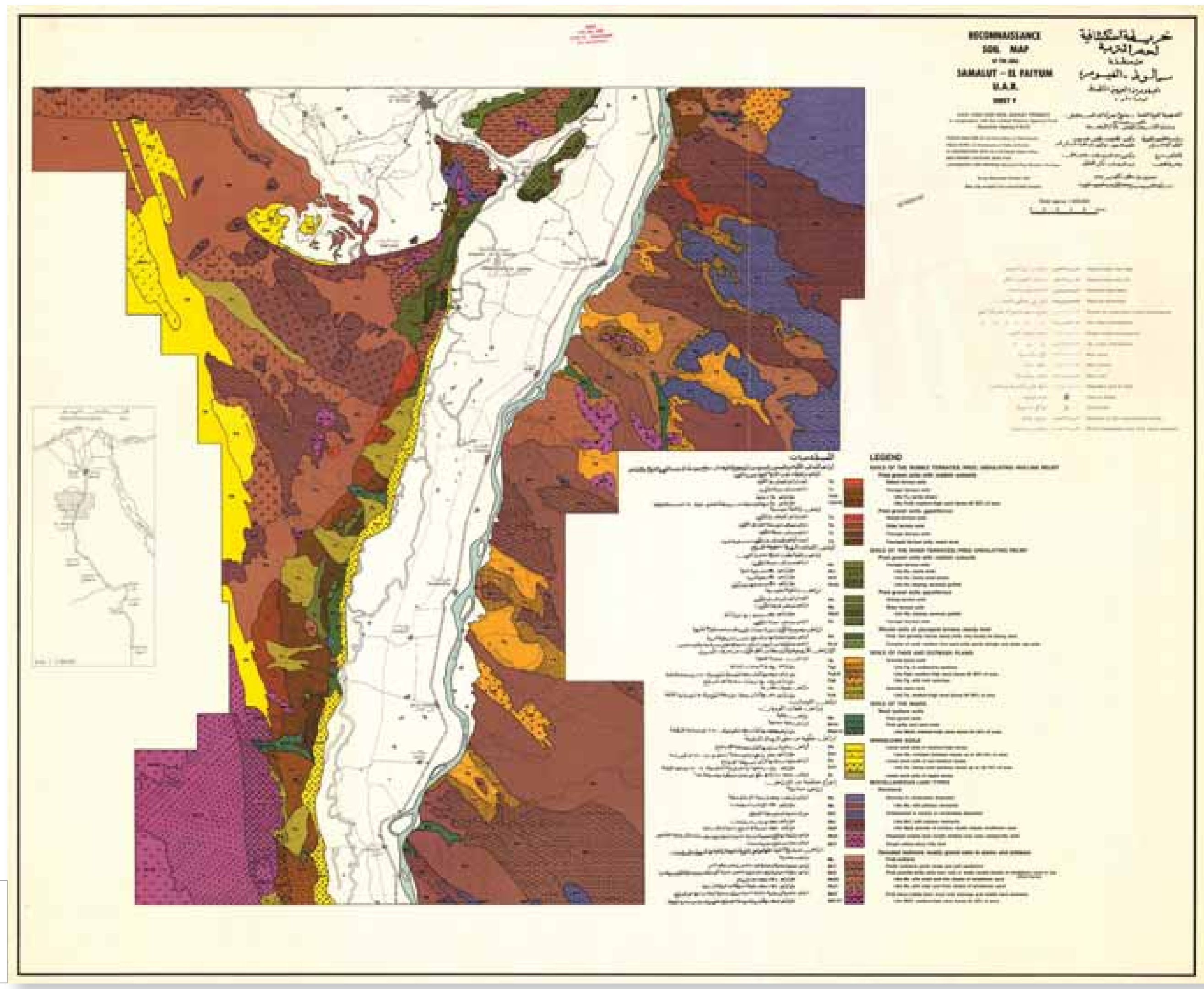
Medium-scale maps

As explained on page 69, soil maps can be prepared at a variety of scales. The maps on the preceding pages show soil patterns across Africa at a scale of 1:3 million (i.e. where 1 cm on the map corresponds to 30 km on the ground). Such maps are referred to as small-scale and provide an overview of general soil patterns over large regions, such as individual countries or an entire continent. Conversely, large scale maps (e.g. 1:50 000 - 1:5 000) cover much smaller areas, such as a region or a town, but in much greater detail.

The use of 'large' or 'small' to describe maps arose from the traditional practice of writing map scales as numerical fractions where a scale of 1:20 000 is larger than 1:20 000 000. Therefore, there is no exact definition of the boundary between large and small scale maps but maps with scales of 1:100 000 - 250 000 are generally considered as being of a medium-scale. In this context, medium-scale maps show more detail for a given area than small–scale maps but may still be too coarse for specific applications (e.g. such as field-level pH).

The maps on these pages are examples of medium-scale soil maps from different parts of Africa. While many are a little dated, the maps clearly show a substantially higher level of detail than the corresponding maps in the preceding pages. Please note that the colours and legends shown on these four examples reflect national soil mapping and classification schemes and may not necessarily match the patterns shown on the smaller scale equivalents shown in this atlas.

The maps on this page (and many others) can be downloaded from the EUDASM, IRD and other map archives (see pages 139).

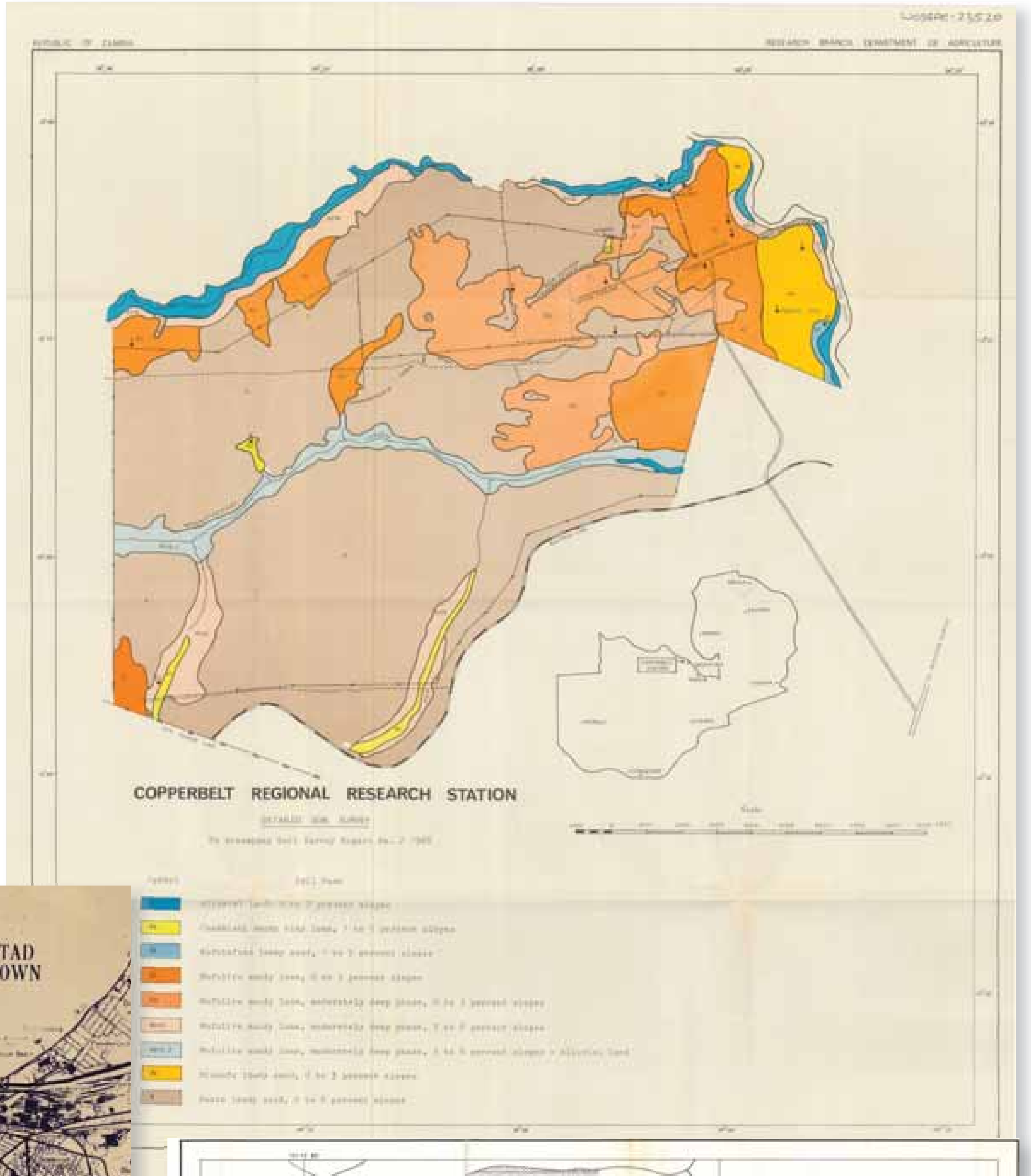


Clockwise, from above, soil maps of: Bangui in the Central African Republic (1:200 000 – 1974: IRD Sphaera No. 849); the Nile Valley just south of Cairo in Egypt (1:200 000 – 1962; EUDASM); coastal region near Accra in Ghana (1:125 000 – 1964; EUDASM); around the town of Atakpamé in the Togo Mountains, eastern-central Togo (1:200 000 – 1979: IRD Sphaera No. 377). [67, 67a]

Examples of large-scale soil maps

Clockwise, from right: detailed soil map from the Copperbelt Region of Zambia – the map differentiates soils on the basis of texture, depth and slope. The alluvial soils are important as rainfall levels in this area are generally low. The map clearly shows the location of soil profile sites. (1:10 000 – 1968; WOSSAC); soil map of a section of the eastern bank of Sanga River near to the town of Nanga Eboko in southeast Cameroon – typical tropical forest soils are interspersed with waterlogged soils in valley bottoms. (1:20 000 – 1966; IRD Sphaera No. 2778); soil map of Table Mountain and surrounding areas, Cape Town, South Africa showing groupings or associations of soils. Again slope and texture, together with parent material, are the main diagnostic elements. (1:20 000 – 1975; EUDASM). [67, 67a]

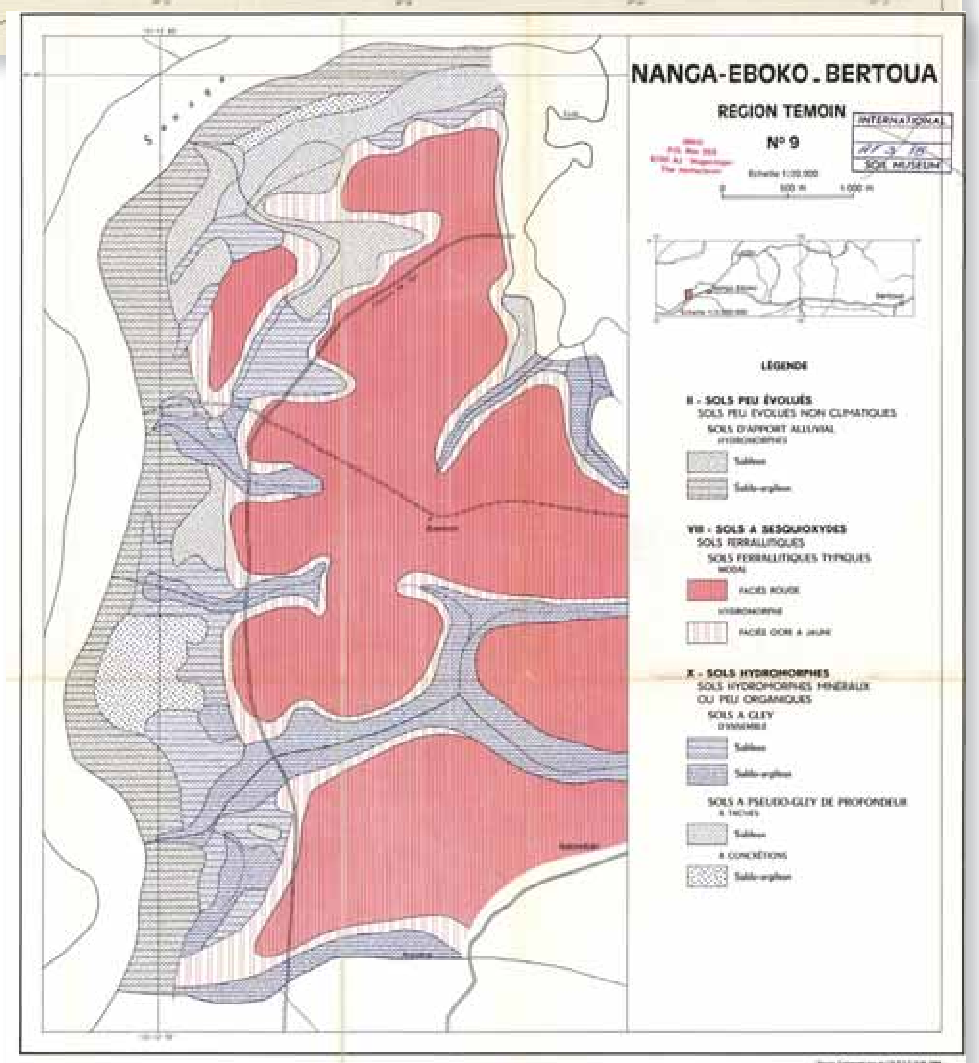
See also the modern 1:50 000 soil map on page 136 of the area around Kinshasa, (Democratic Republic of Congo) produced using GIS technology.



Large-scale maps

Large-scale maps generally have a scale of 1:50 000 or greater (e.g. 1:24 000; 1:10 000; 1:5 000). A large-scale map shows greater detail for a relatively small area (e.g. 100 x 100 km, 10 x 10 km) and as the scale increases, the soil pattern in individual fields becomes more and more evident. For example, on a 1:10 000 scale, 1 cm on the map corresponds to 100 m on the ground.

By definition, the creation of these maps entails a significant amount of effort to acquire the necessary source data. As a consequence, they tend to be produced only where the principal land use is agriculture. Large-scale maps are used to support land evaluation or the implementation of land use planning policies.



Soil mapping in Rwanda: a model for Africa?

This atlas has shown the importance of understanding the spatial distribution of soils and their properties. This is especially true for agricultural development and a more rational management of land resources, particularly in response to issues such as ongoing land degradation and decreasing yields. To be effective for such purposes, soil data should be available at medium- to large-scales (preferably > 1:50 000). However, this level of detail is lacking for most of Africa. The situation is compounded by the fact that the detailed data that do exist are often more than 50 years old and systematic soil survey is not being carried out to collect more up to date data.

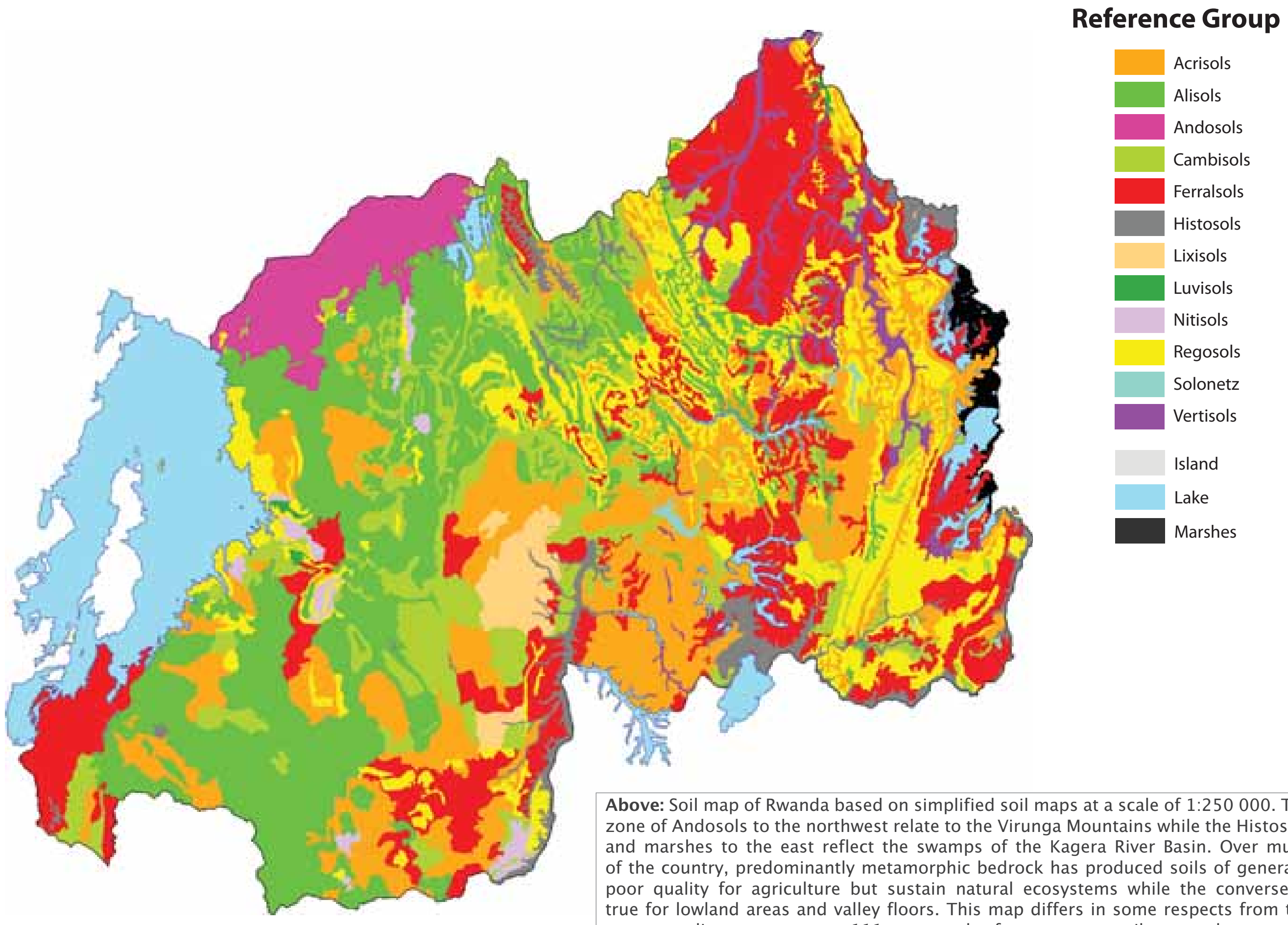
A country which stands out in this respect is Rwanda. Not only is there a complete and detailed soil inventory of the country, the data have been digitised and can be viewed and queried over the internet. In this respect, Rwanda could be a model for other African countries.

Between 1981 and 1994, the Rwandan Ministry of Agriculture, Livestock and Forestry and the Belgian government cooperated to develop a national soil map of Rwanda (the Carte Pédologique du Rwanda) at a scale of 1:50 000. This detailed soil survey was based on the elaboration of a physiographic map, a reconnaissance survey along with extensive use of aerial photographs and supporting fieldwork. The soil units mapped were mainly associations or complexes of soil series. More than 2 000 soil profiles, corresponding to 176 different soil series, were described and analysed for key soil properties. The base maps for the soil survey were forty-three topographic map sheets at a scale 1:50 000. These maps contained contour lines at an interval of 25 m. Additionally, they contained the boundaries and names of the administrative units at different levels (provinces, villages) together with the hydrologic network, the road infrastructure and main land use.

From 1989 onwards, the soil maps and all observation points (i.e. profiles and augers) and corresponding data were digitised and stored in a database for further elaboration (see page 136). Each soil unit received a unique label that was related to a database containing the tabulated properties of each soil series. A legend was designed to group the different soil units according to their parent material, profile development, depth or drainage, texture and stoniness. Due to the war in Rwanda, the project was temporarily stopped in 1994, before being finally completed by Ghent University, Belgium, between 1998-2000.

The soil data were complimented with topographic data and climatic records while the generation of simplified soil maps at a scale of 1:250 000 illustrated the diversity in land resources at national level. The resulting database has become the key instrument for the description of the physical environment that farmers face in the different agricultural regions of the country and for the evaluation of the agricultural potential.

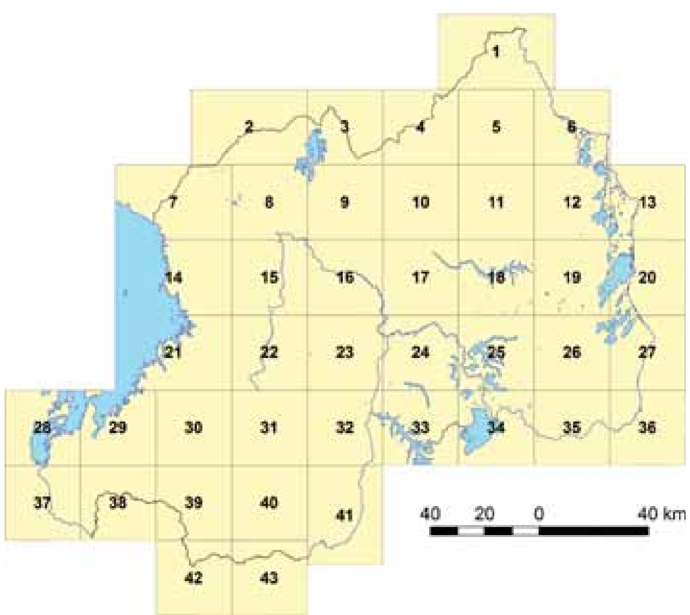
Such information is also important for urban planning, hazard assessment and the development of high-input agriculture schemes. The system allows for easy updating, modification or reorientation depending on the requirements of the different policy sectors. [68]



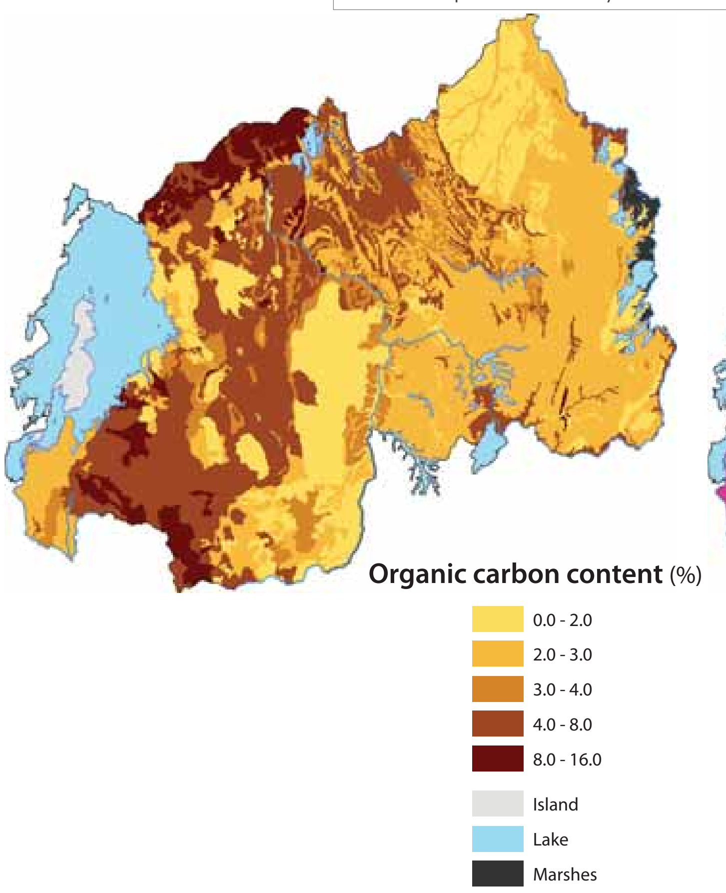
Above: Soil map of Rwanda based on simplified soil maps at a scale of 1:250 000. The zone of Andosols to the northwest relate to the Virunga Mountains while the Histosols and marshes to the east reflect the swamps of the Kagera River Basin. Over much of the country, predominantly metamorphic bedrock has produced soils of generally poor quality for agriculture but sustain natural ecosystems while the converse is true for lowland areas and valley floors. This map differs in some respects from the coressponding map on page 111 as a result of more recent soil survey, larger scale source data (1:50 000) and a reinterpretation of soil characteristics. (EVR/AV)

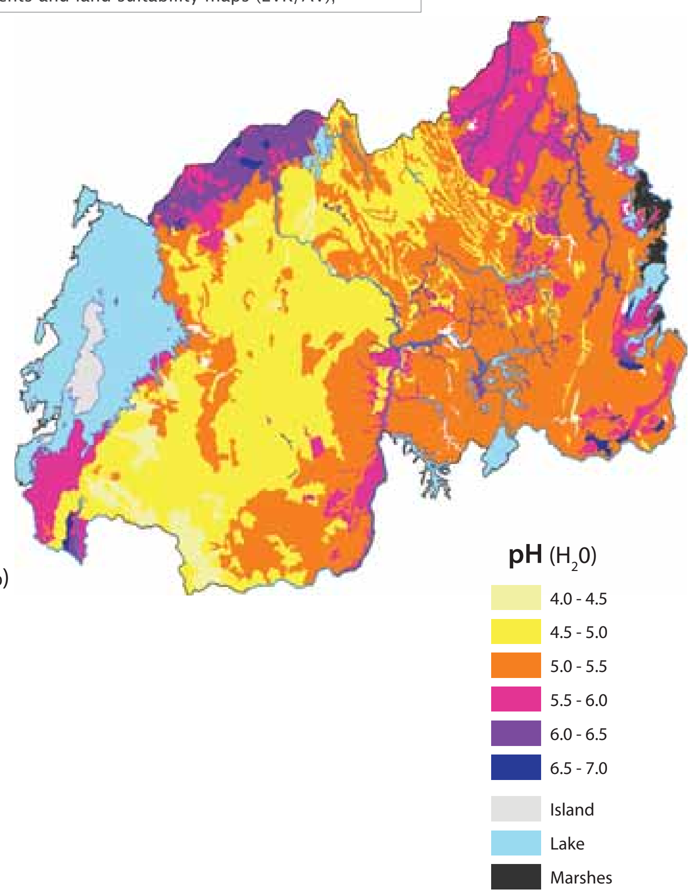
Below: Expanded detail of the 1:50 000 soil map of Rwanda from an online map viewer with a query result from the underlying database (http://zadeh.ugent.be/rwanda/#). (EVR/AV) [68a]

Maps of soil organic matter (**below left**) and pH (**below right**) for Rwanda – such maps can be used as inputs to soil fertility assessments and land suitability maps (EVR/AV);



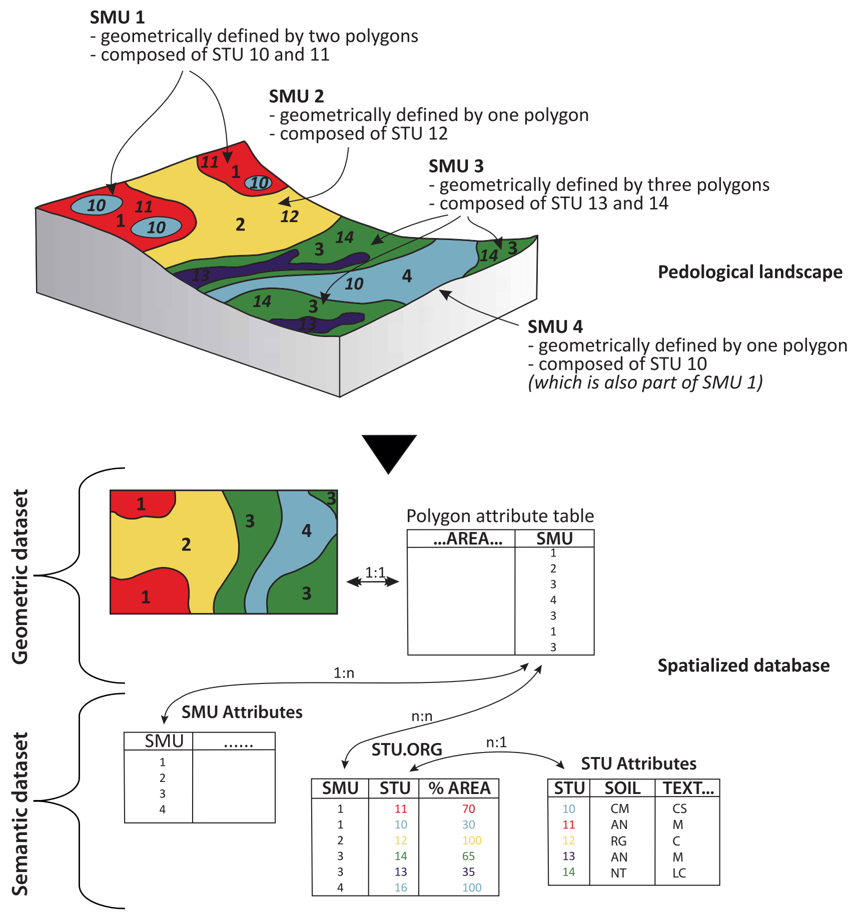
Index to the forty-three 1;50 000 map sheets covering Rwanda. (EVR/AV).



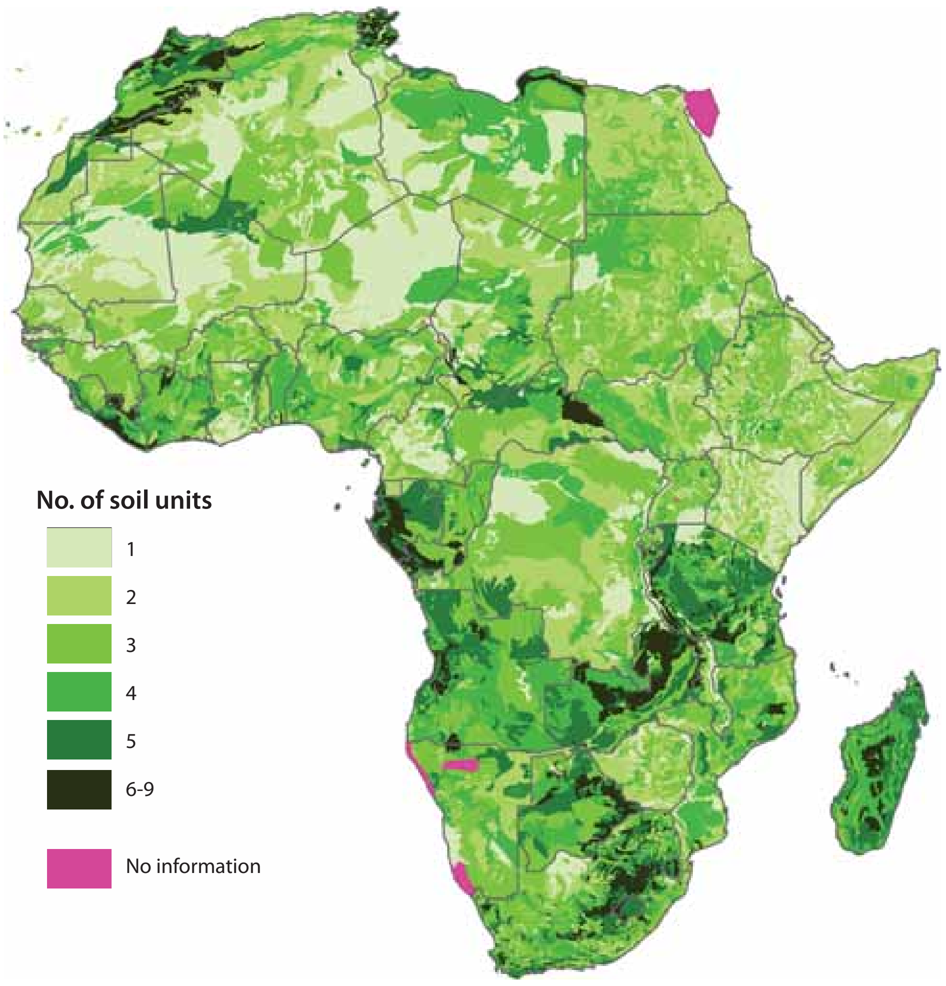


Maps of key soil properties

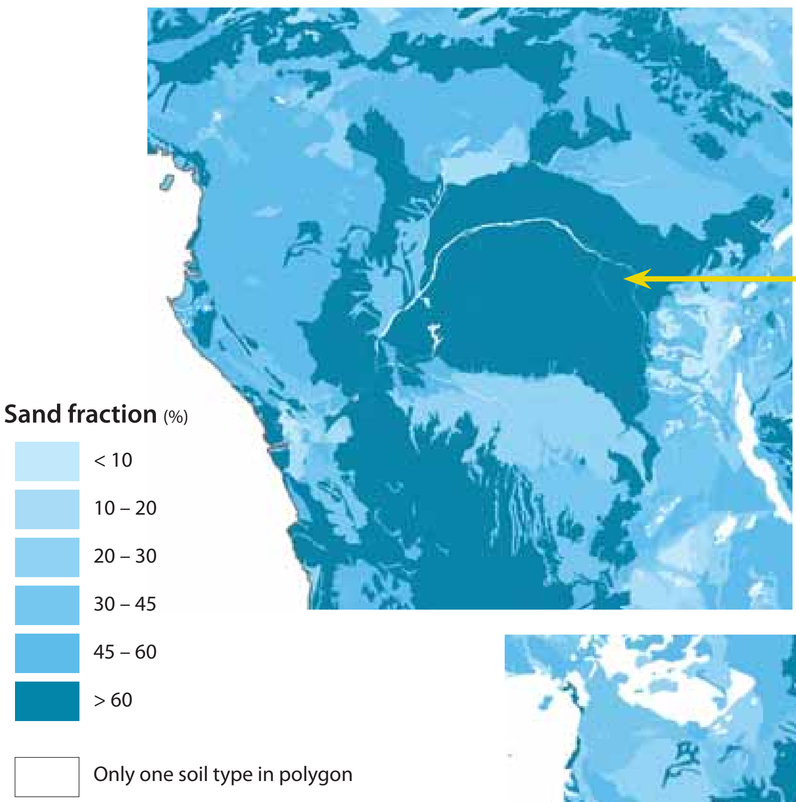
The following pages present a series of overview maps describing key soil properties across Africa. The maps have been prepared from data contained in the Harmonized World Soil database (see page 136) [69]. The very small scale used in these maps will inevitably mask specific local conditions. However, the general regional patterns are valid and representative of overall conditions.



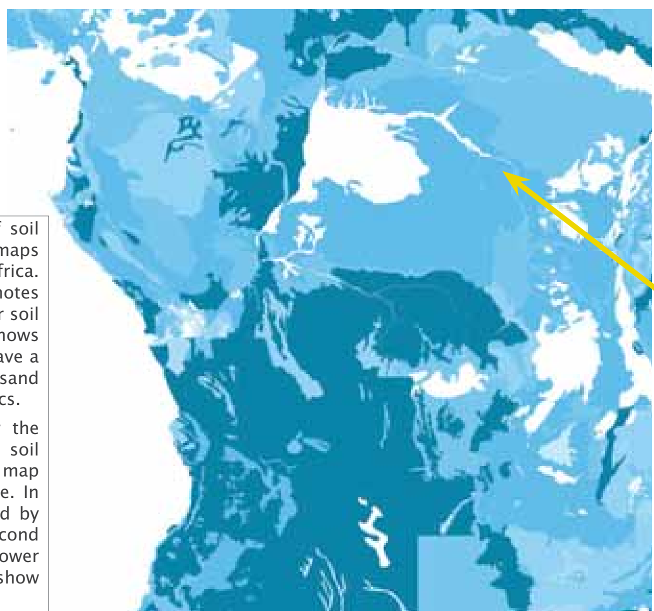
The Harmonised Soil World Database uses a simple relationship model to link a geometrical dataset (grid cells) and a semantic dataset (information on soil properties). The diagram illustrates how a geographical representation of soil and landscape patterns (known as Soil Mapping Units or SMUs) are linked to specific data on soil types (referred to as Soil Typological Units or STUs in this figure). Try and follow the diagram to understand that polygon 1 from the digital map (the red area), corresponds to SMU 1, which consists of two soil types (STU 10 and STU 11), which occupy 30% and 70% of SMU 1 respectively. In this example, analysis of the relationship table (STU.ORG) and the STU attribute table would show that the dominant soil of SMU 1 is STU 11, an Andosol (AN). (JDR/SH)

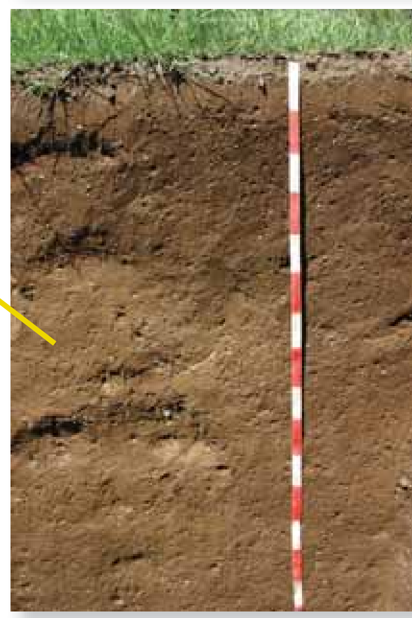


The map shows the variability of soil information in the database for Africa. As shown by the adjacent figure, each cell in the Harmonized World Soil Database can contain up to nine soil types. While the geographic locations of the component soil types within each cell are not defined, the database stores the typical proportion that each one occupies. When the mapping unit is composed of only one soil type, this percentage is equal to 100. When there are several soil types, then the sum of the percentages is equal to 100%. Areas with lighter tones (e.g. the Sahara) exhibit a lower number of soil types per mapping unit while darker areas (e.g. Gabon, South Africa) have more. It should be stressed that this variability is usually a reflection of the level of soil survey in a region as much as than the actual diversity of soil types. In the case of the following property maps, data are presented for the dominant soil type within each cell (i.e. the soil having the highest percentage of area). However, it should be noted that only a proportion of the grid cell will have the assigned characteristic (unless there is only one type of soil!). (JRC)



The dominant soil for the polygon indicated by the arrow (central Congo) is a sandy Ferralsol. (OS)



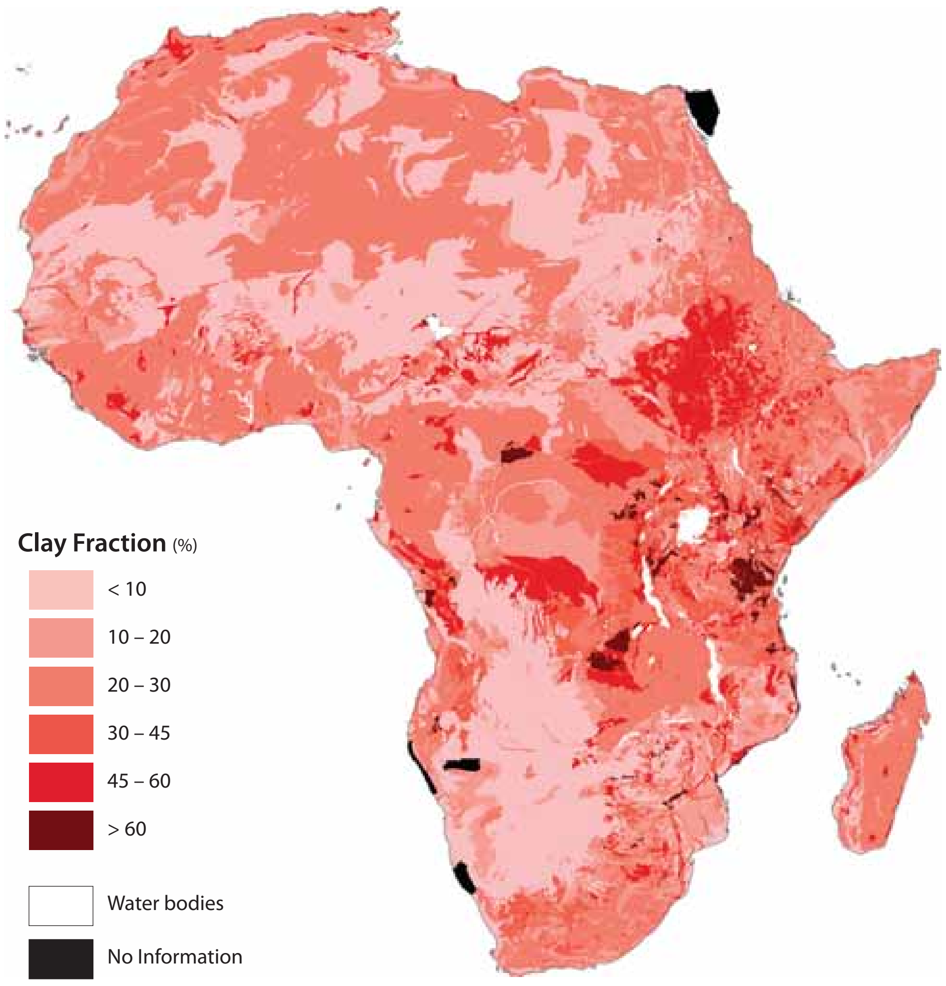


The second dominant soil for the same polygon is a Cambisol. (EM)

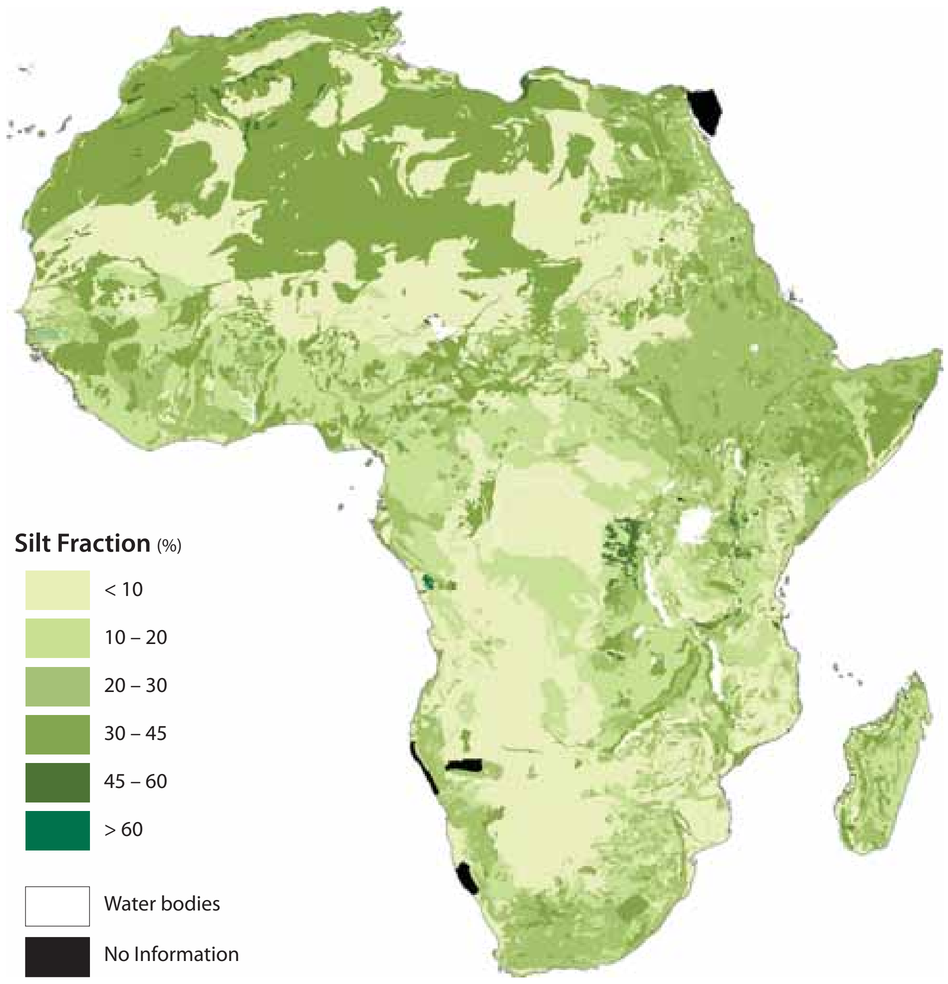
This pair of maps is a clear example of how the depiction of soil properties can vary according to the selection of soil type. Both maps show the proportion of sand particles in the topsoils of central Africa. Note the resultant change in patterns. The darker shading denotes high levels of sand-sized particles in the soil (and thus a coarser soil texture) than areas with lighter tones. In this manner, the maps shows that some areas (e.g. the Congo Basin and northern Kalahari) have a high sand content while in other areas (e.g. parts of Uganda), the sand content is much lower, indicating very different soil characteristics.

The upper map shows the proportion of sand particles for the dominant soil type (see facing page for full map). This is the soil type that occupies the largest area of each polygon. The lower map shows the same information for the second dominant soil type. In this example, the dominant soil type for the polygon indicated by the arrows has >60% sand fraction in the topsoil, while the second dominant or associated soil in the same polygon has a slightly lower level (45-60%). All maps presented on the subsequent page only show information for the dominant soil type.

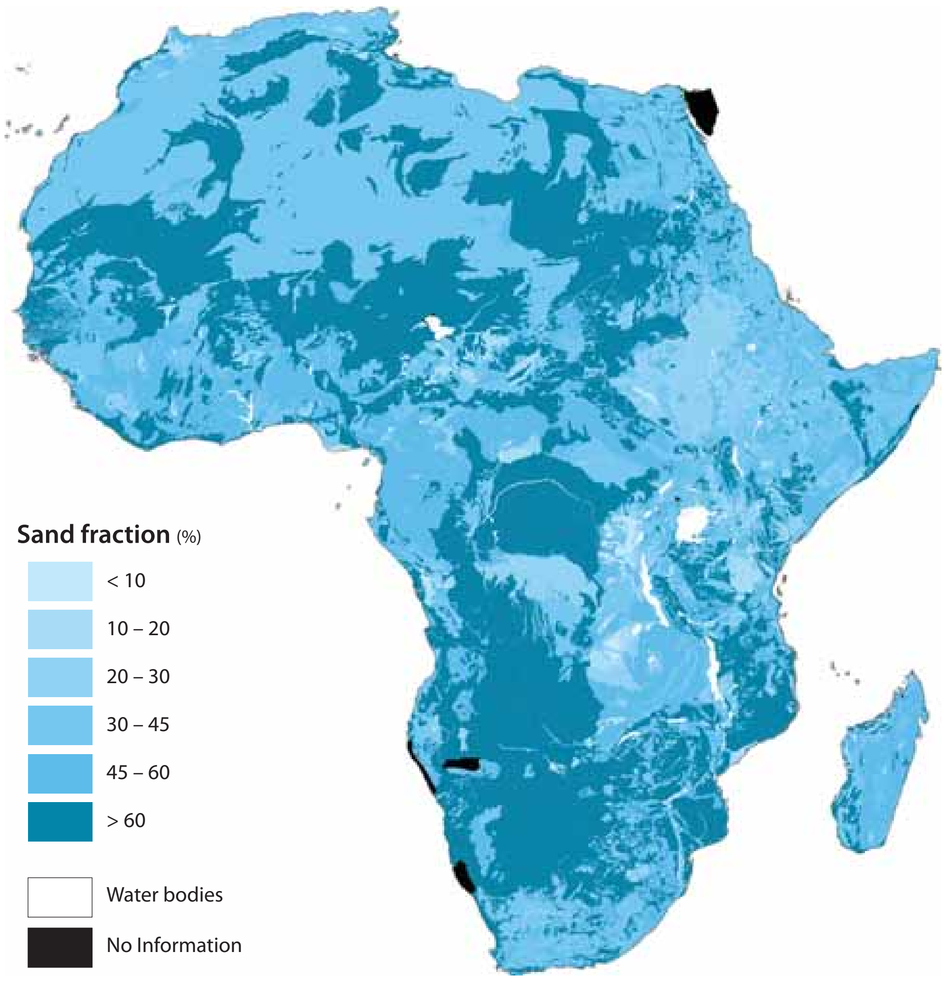
The white areas on the map indicate regions where only one soil type has been recorded in the database. (OD)



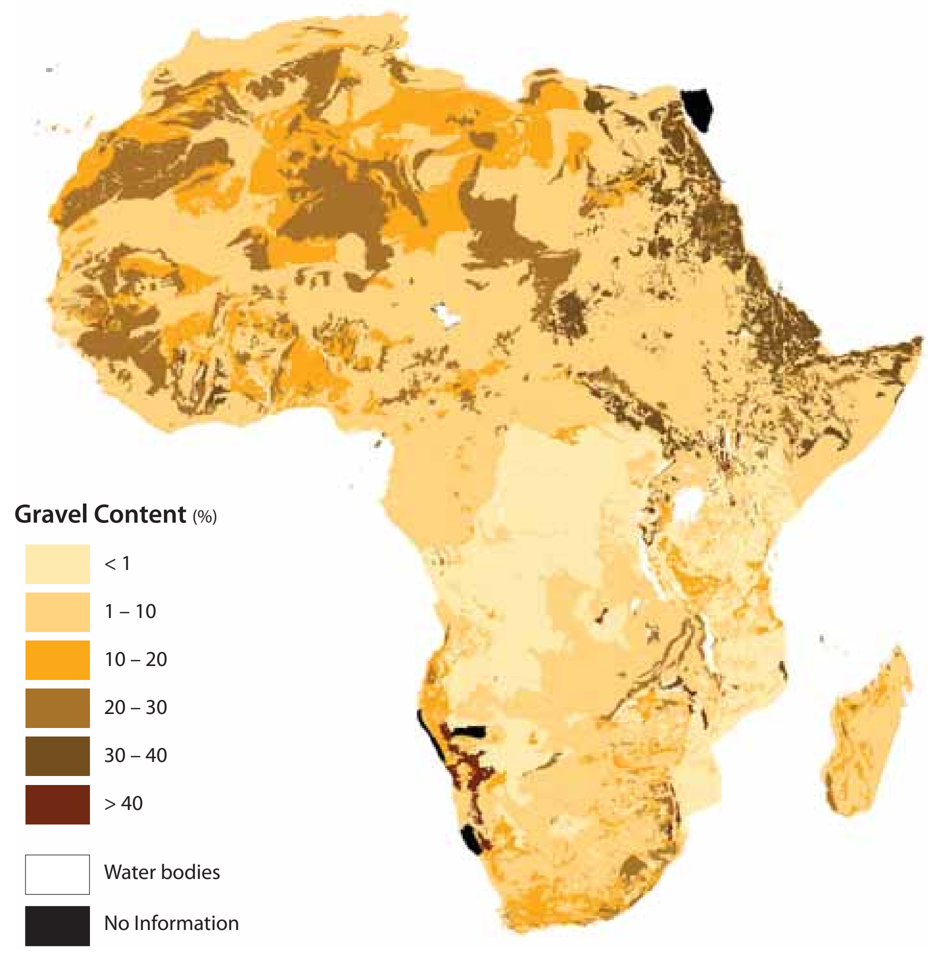
The proportion of clay particles in the topsoil (i.e. mineral matter less than 0.002 mm in diameter). These tiny particles require microscopes to see them. The soil feels smooth when rubbed between one's fingers. Clay-rich soils tend to contain more nutrients and because of their very high surface area can retain large amounts of moisture. As a result, they are favoured for agriculture. However, they can be difficult to cultivate when wet as they become very heavy and slow to drain. Can become very hard when dry. Particularly apparent on the map are the expanses of Vertisols, Gleysols and saline soils. High clay content is generally indicative of the chemical weathering (and associated transport) of parent material. (OD)



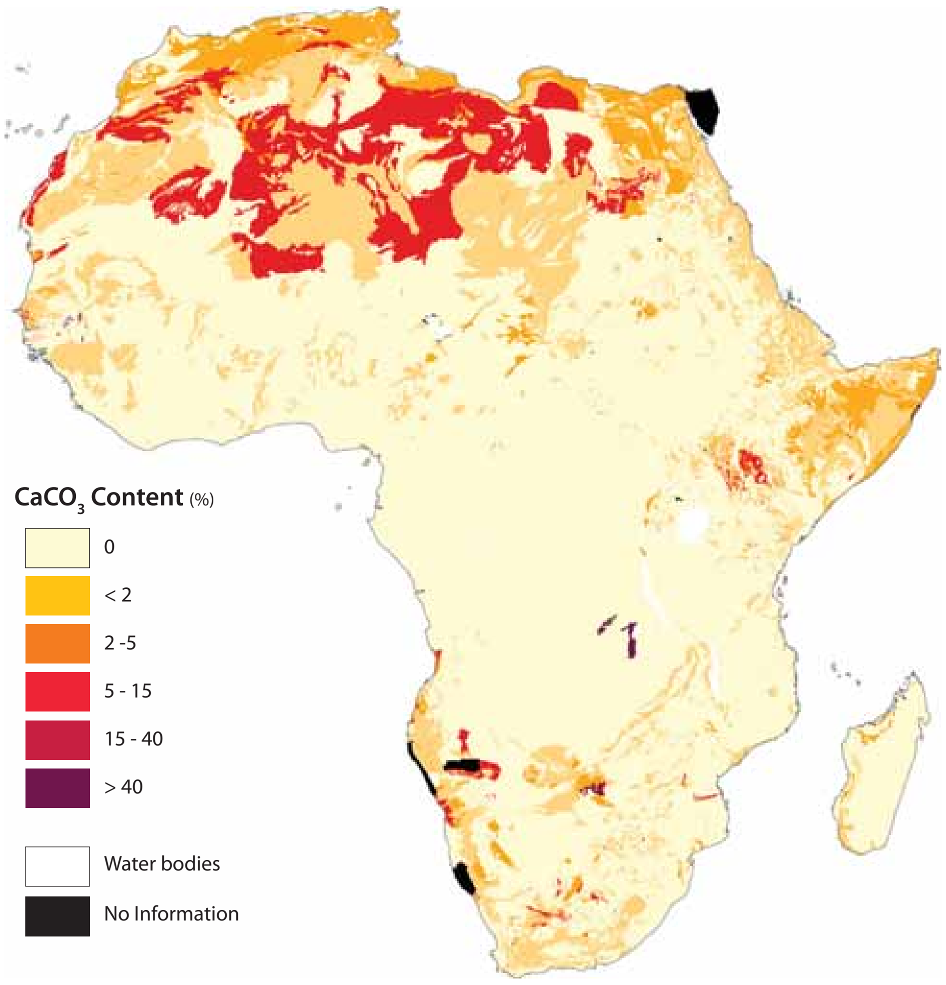
The proportion of silt particles in the topsoil (i.e. mineral matter between 0.002 mm and 0.05 mm - USDA classification - or between 0.002 mm and 0.0625 mm - ISO and FAO classification). Silt is too small to see with the naked eye. It is produced by the mechanical weathering of rock, as opposed to the chemical weathering that results in clays. This mechanical weathering can be due to aeolian abrasion (sandblasting by the wind) as well as water erosion of rocks on the beds of rivers and streams. It is good agricultural soil due to high nutrient levels and good water retention in spaces between particles. Easy to cultivate but very prone to erosion. (OD)



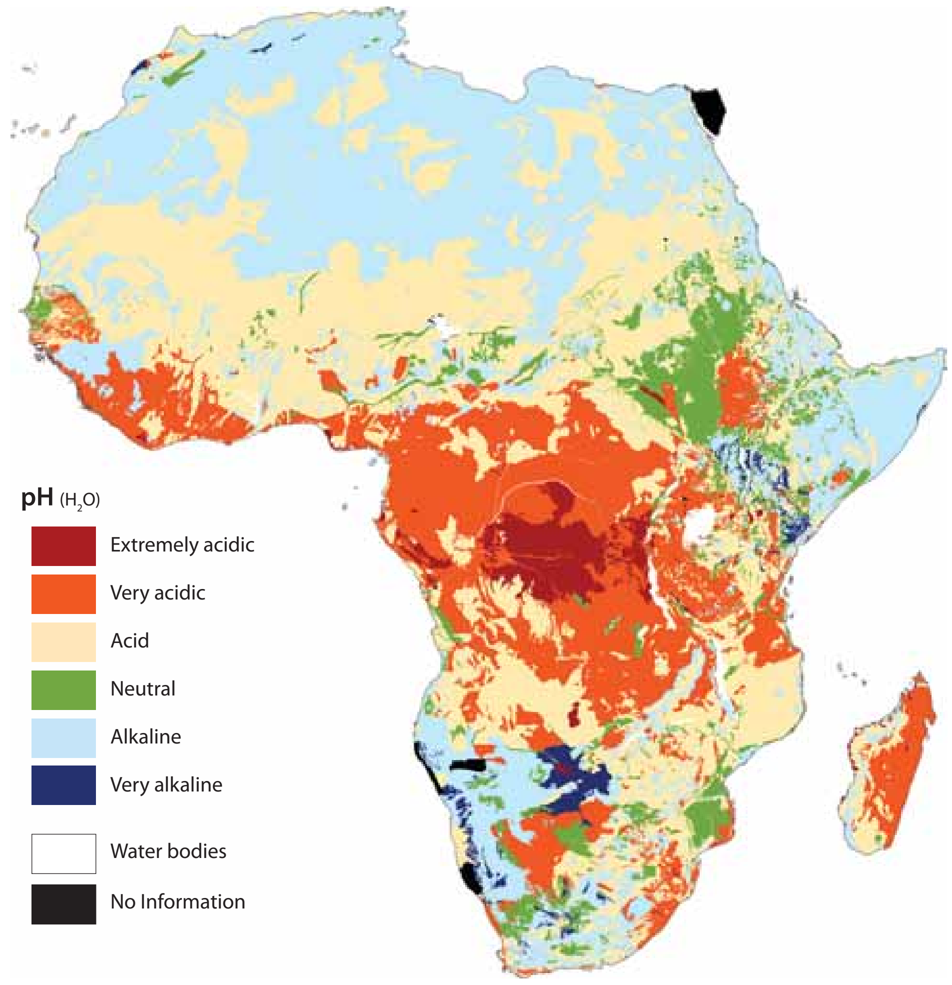
The proportion of sand particles in the topsoil (i.e. mineral matter between than 0.05/0.0625 mm and 2.0 mm in diameter). Most sand grains consist of quartz and are visible to the naked eye. Sand feels gritty when rubbed between the fingers (silt, by comparison, feels like flour). Sandy soils are very easy to cultivate but are generally lacking in nutrients and have low water-holding capacity, making them susceptible to drought conditions. As a result of the large volume of spaces between grains, water is easily drained away. Sand is commonly divided into five sub-categories based on the size of particles: very fine sand, fine sand, medium sand, coarse sand and very coarse sand. The map highlights the sand seas of the deserts (Arenosols) and the coarse grained Ferralsols of the tropics. (OD)



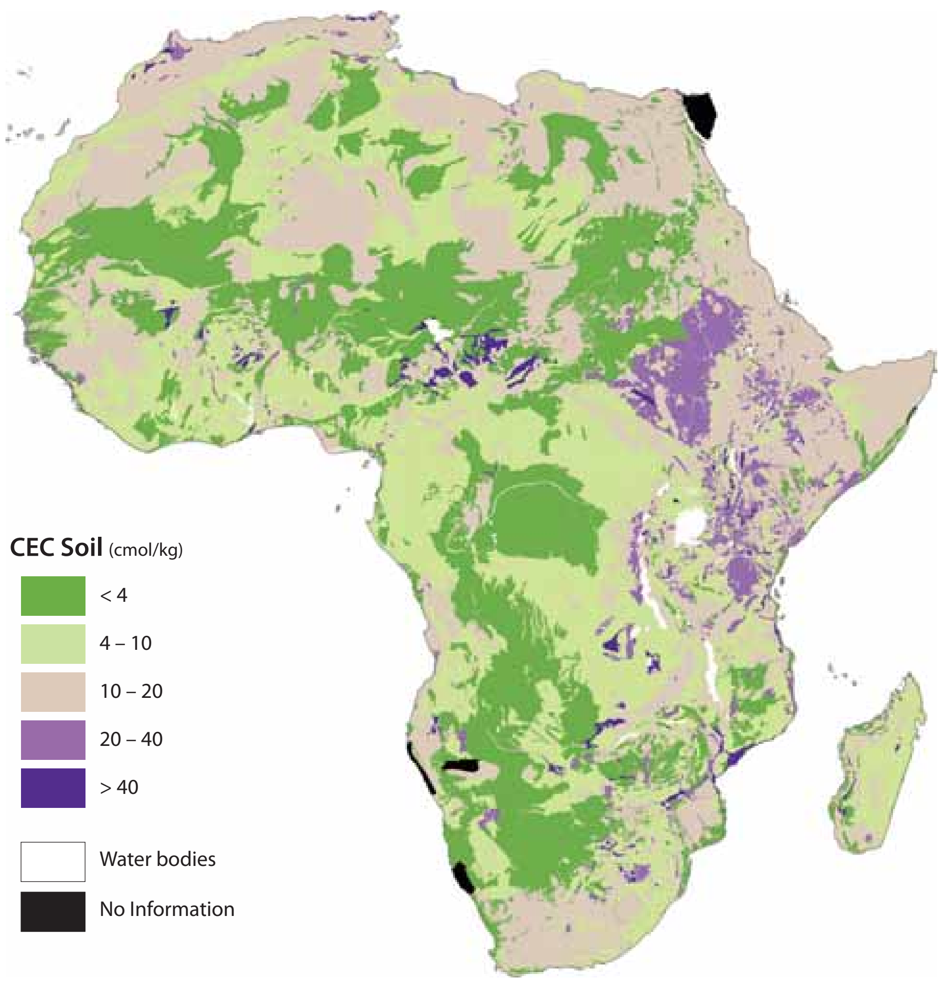
Gravel is generally defined as rounded or angular fragments of rock between 2 mm and 6 cm in diameter and is an indication of the stoniness of the soil. In general, a high gravel content can be an indication that the parent material is close to the surface. The Sahara, the Sahel and most soils on the old geological mantle in the west of the continent are gravelly, particularly those which are associated with iron caps and debris slopes in course of weathering. While some forms of agriculture (e.g. vineyards) prefer gravelly soils, a high proportion of stones in the soil is generally less desirable due to low water retention, nutrient levels and difficulties during tillage. Some stony soils may support distinctive ecological habitats. (OD)



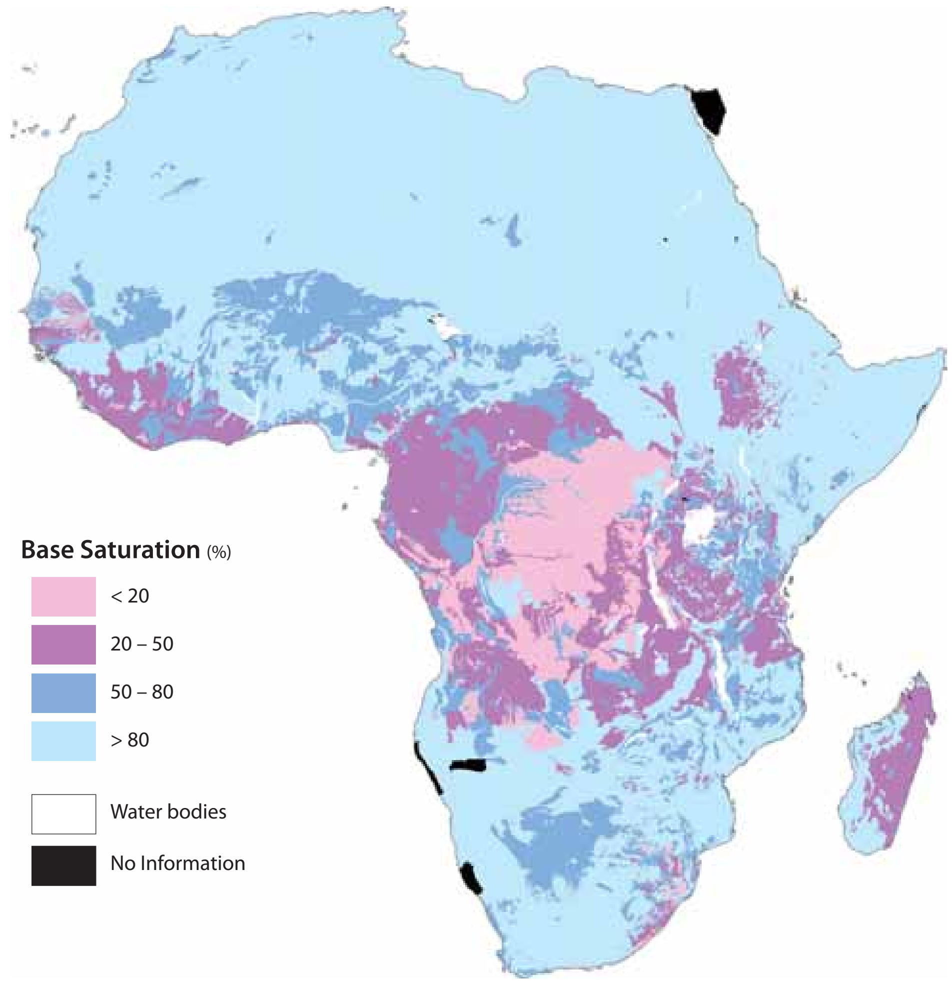
Calcium carbonate is a compound (actually a salt), with the formula $CaCO_3$. It is a common substance found as rock in all parts of the world and is the main component of shells of marine organisms, snails and eggshells. Calcium carbonate is the active ingredient in agricultural lime and is usually the principal cause of hard water. Calcium carbonate is quite common in soil, particularly in drier areas where it may occur in different forms. Low levels of calcium carbonate enhance soil structure and are generally beneficial for crop production but at higher concentrations they may induce iron deficiency and, when cemented, limit the water storage capacity of soils. (OD)



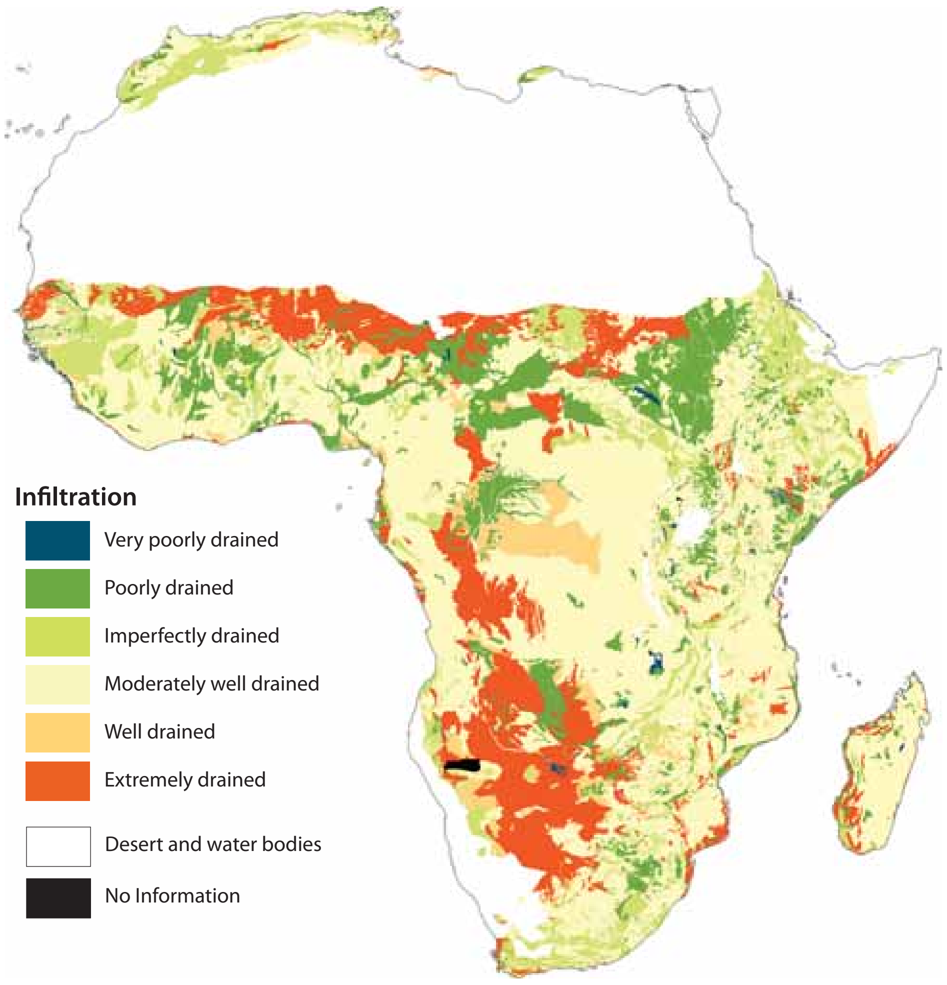
pH is a numerical designation of acidity and alkalinity in soil (see page 11). pH 7 is regarded as neutral with lower values being acidic and higher values alkaline. Soil pH is considered a critical parameter as it controls many chemical processes. Of key importance is its influence on plant nutrient availability. The optimum pH range for most plants is between 6 and 7.5. However, many plants have adapted to thrive in values outside of this range. Acid soils are mostly found in areas of high rainfall where the more mobile base cations are leached from the soil, increasing the levels of Al^{3+} and H^+ cations. Alkaline soils are characterised by the presence of soluble salts. The calcium carbonate map (left) shows the distribution of lime bearing rocks – the application of lime to acid soils can raise pH values and allow the cultivation of additional crops – notably absent in central Africa. (OD)



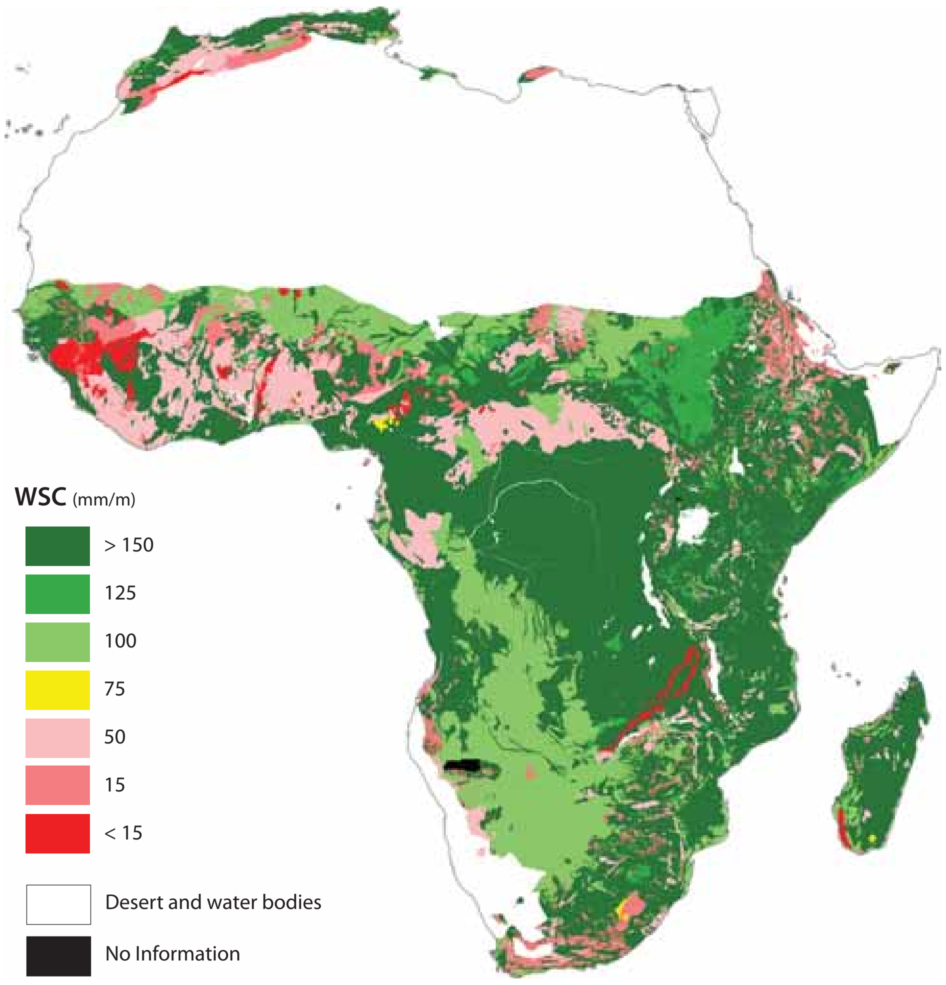
Cation exchange capacity (CEC) is the total amount of exchangeable cations that can be held by the soil and is an indication of a soil's nutrient status. Positively charged ions of elements such as calcium, aluminium, potassium and sodium that are bound to negatively charged soil particles can be replaced (i.e. exchanged) by hydrogen cations in the soil solution. Once in solution, the nutrient is available to plants. Soils with low CEC have little resilience and cannot build up stores of nutrients. Many sandy soils have CEC less than 4 cmol kg^{-1}. Values in excess of 10 cmol kg^{-1} are considered satisfactory for most crops. Increasing the organic matter content of any soil will help to increase the CEC. (OD)



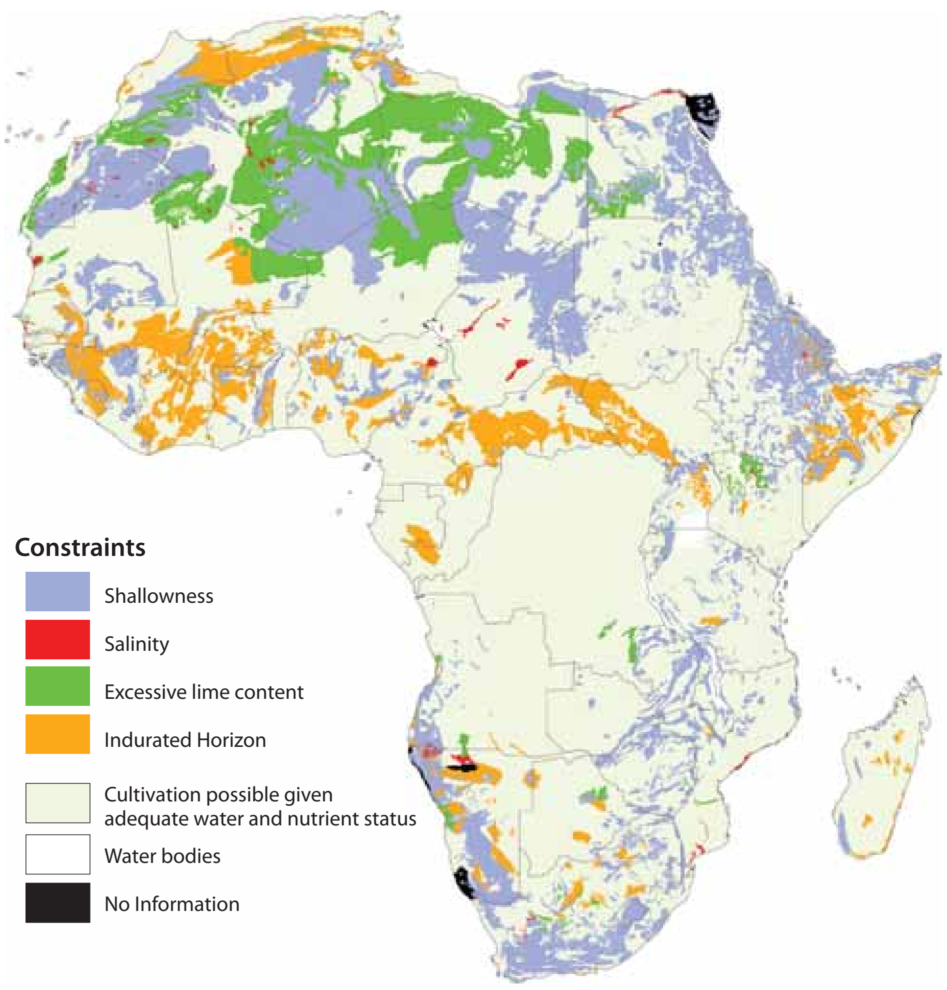
The exchangeable cations in a soil can be divided into two groups: base cations which are alkaline and therefore raise the soil pH (e.g. Ca^{2+}, Mg^{2+}, K^+, Na^+) and acid cations which increase soil acidity and therefore lower pH (e.g. H^+, Al^{3+}). To maintain the soil's charge neutrality, every potential binding site must have a cation bound to it. Whichever type predominates these exchange sites determines the soil pH and acidity levels. Base saturation measures the sum of exchangeable cations as a percentage of the overall exchange capacity of the soil. The value often shows a near linear correlation with pH. (OD)



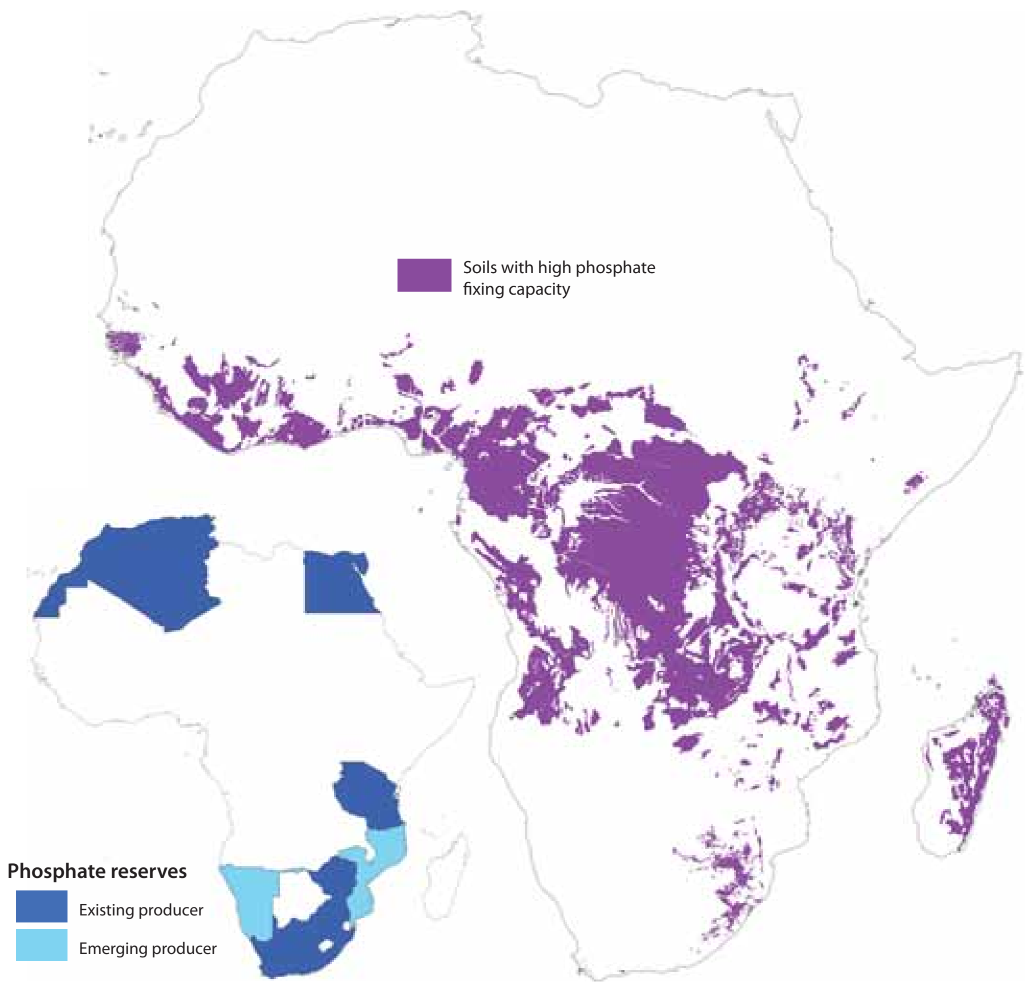
Infiltration is the process by which water on the ground surface enters the soil. The rate of infiltration decreases as the soil becomes saturated. If the precipitation rate exceeds the infiltration rate, runoff will usually occur. In extremely drained areas, water is removed from the soil very rapidly (commonly very coarse textured, rocky or shallow soils, often on steep slopes). Conversely, on very poorly drained areas moisture is removed from the soil so slowly that free water remains at or on the surface during most of the growing season. In the former case, soils tend to have insufficient water-holding capacity to support crops while in the latter case, unless the land is artificially drained, most crops cannot be grown due to a lack of oxygen in the root zone. For this map, arid areas are not considered due to low precipitation levels. (OD)



Water storage capacity (WSC) is the amount of water that a soil can store. It is not the portion of water that can be absorbed by plant roots, which is plant specific. It is commonly defined as the difference between the amount of water contained in the soil at field moisture capacity (i.e. a saturated soil where all the space in the soil is filled by water) and the amount at wilting point (i.e. the least amount of soil moisture that a plant requires not to wilt, beyond which a plant can no longer recover its rigidity). It is commonly expressed as millimetre of water per metre of soil. Traditionally available water capacity is calculated for the nominal root depth. The available water content depends greatly on the soil texture and structure. Organic matter increases the available water capacity. Every 1% of organic matter adds about 1.5% to the available water capacity. For this map, arid areas are not considered due to low precipitation levels. (OD)



This map show areas where the soils have major constraints to the their use, especially for cultivation. Four main issues are addressed: shallow soils (insufficient rooting depth, nutrient levels and/or water storage capacity), salinity (high levels of salts are toxic to many plants), the presence of indurated horizons within the soil (secondary accumulation of substances such as silica, iron, gypsum and lime can restrict the effective soil depth or its cultivation) and high levels of calcium carbonate (which can lead to plant toxicity, textural problems and crusting). All these constraints can affect soil fertility and productivity (see pages 34-35). (OD)



Map showing the main areas of soils with high fixation capacity of phosphate across Africa. Phosphorus is an important nutrient for plant growth. However, phosphorus deficiency is often observed in many tropical soils. This is due to the elevated affinity of soil particles, such as iron and aluminium (and their oxides) or organic matter, to remove compounds such as phosphorous from solution to a solid phase and form insoluble compounds that are unavailable to plants (a process known as sorption). Phosphorus is particularly immobile in Acrisols, Andosols, Lixisols, Ferralsols and Nitisols. Liming to correct the soil pH is critical for P availability together with regular, but small, applications of phosphorus fertiliser. (JRC). The inset map shows the main and emerging phosphate producing countries of Africa [33]. Notice the disparity between areas with high phosphate need and sources of phosphate reserves! (JRC)

Producing the soil maps for the atlas

Geographic Information Systems and the Harmonized World Soil Database

What is a Geographic Information System?

All the maps contained in this atlas, have been produced using a technology known as Geographic Information Systems or GIS for short.

A GIS can be defined as a specialised computer system (both hardware and software) for capturing, storing, checking, merging, manipulating, analysing and displaying data which can be located somehow on the surface of the Earth. In geography, the term 'spatial' is used when referring to such data. Latitude and longitude coordinates, map references, administrative regions, water bodies and settlements are some of the means of relating information to a particular location. In this respect, a GIS is different from a Computer Aided Design (CAD) programme which stores information on features in an abstract space.

Features such as roads, rivers, soil types, or water quality sampling sites are represented in a GIS in digital form as points, lines (arcs), polygons (areas) or as cells (a grid).

Descriptive information or attributes about objects (e.g. names, ownership, depth, soil type) can be associated with the geographical data. This 'descriptive' information is normally stored in the form of tables in a database and is linked to the geographic or map data by a common identifier.

For the most part, spatial data can be converted from one coordinate system into another, thus data from various sources can be brought together into a common database and integrated using GIS software. In this way, a global database on soil profiles using latitude and longitude to mark sampling sites could be combined with soil data compiled on the basis of maps using a national coordinate system.

Spatial data and associated attributes in the same coordinate system can be viewed together and layered on top of each other to create maps.

Higher level analysis can also be carried out on data. Questions such as "What would happen if...pollution accidentally leaked into a sandy soil?", "Where does...a podzol occur next to arable land?" or "Is there a pattern to...landslide events in a national park?" are only feasible on large volumes of information by using a GIS. More complex queries could entail identifying potentially fertile soil in semi-arid areas on flat terrain that is within 200 m of a water source in order to assess irrigation potential.

A further key component of a GIS is the human element. Well-trained people, knowledgeable in spatial analysis and skilled in using GIS software are essential to the GIS process.

GIS is being used by more and more organisations. Originally developed primarily as a research tool for geography departments of universities, the use of GIS is now widespread in facilities management (e.g. water pipes, electricity cables), marketing and retailing (e.g. optimising store location with respect to customer needs), the military (e.g. battlefield maps, terrain evaluation), environmental management (e.g. predicting floods, erosion risk, forest fires), transport (e.g. vehicle routing, noise surveys), health (e.g. relationship between illnesses and social or environmental factors) and many, many more sectors.

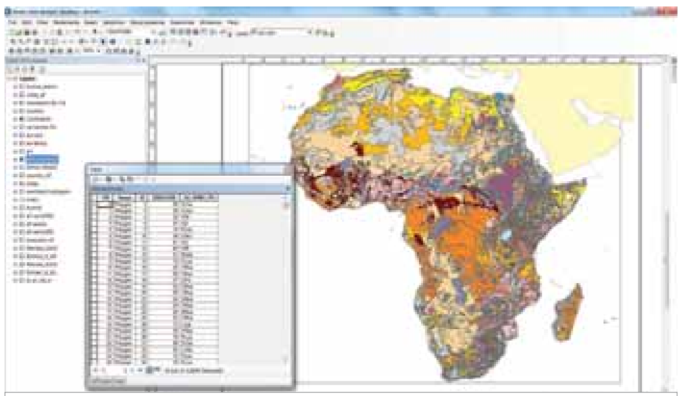
The GIS software used in the production of the maps in this atlas is a product called ArcGIS developed by ESRI Inc. from Redlands, California.

If you would like to learn more about spatial data and Geographic Information Systems, have a look at the following sites on the worldwide web:

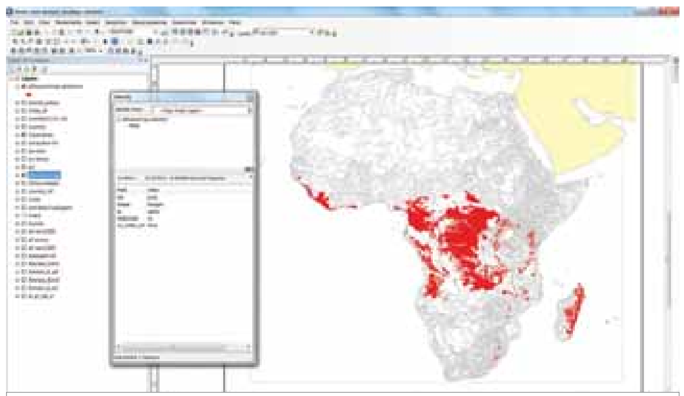
http://www.gis.com

http://tinyurl.com/bwqe4ny

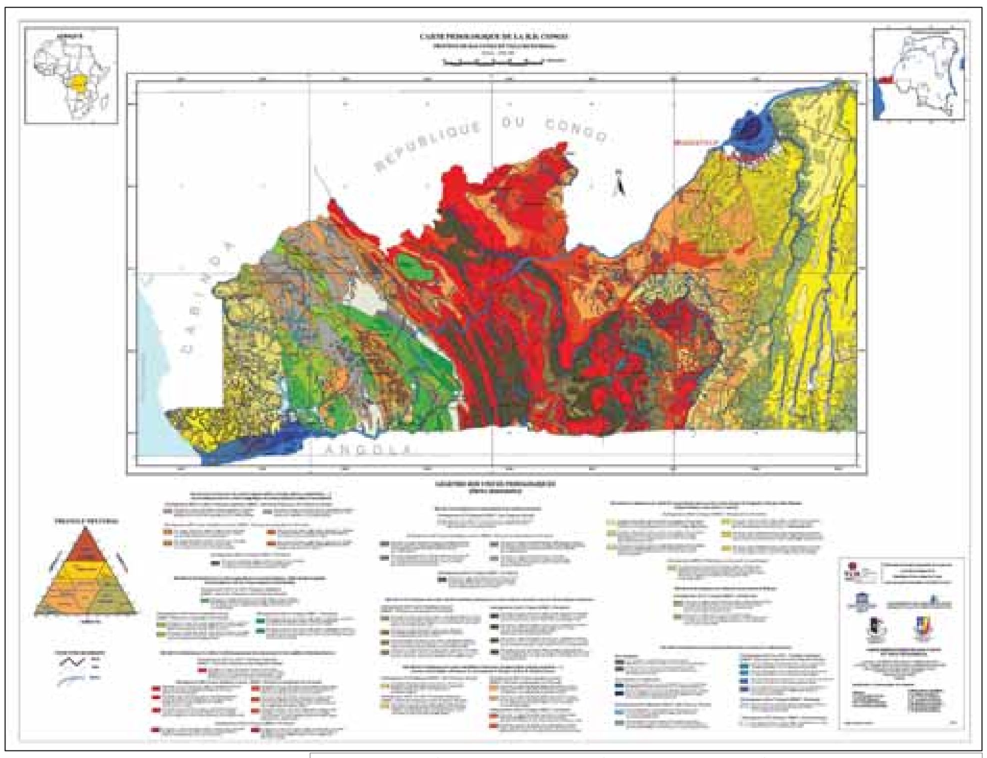
http://www.usgs.gov



The picture shows the interface to the GIS software used to produce the maps in this atlas. The digital cartographic data (map) have been coloured using a legend based on codes indicating the WRB Reference Group. The small window displays the attribute table for the map data. Each polygon or area has been coded with the appropriate WRB code and a unique identifier to link the attribute data to the graphics. (JRC)



The picture shows how GIS software can be used to query or search spatial data and display the results. The map shows the location of all polygons containing the code FR in the WRB-GRP column of the attribute table. In effect, the map shows the distribution of undifferentiated Ferralsols (JRC).

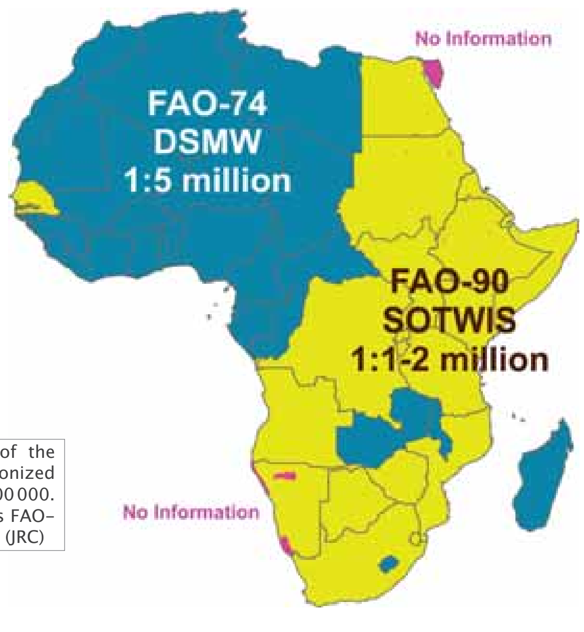


An example of a recent soil map of the western part of the Democratic Republic of Congo where a GIS has been used to store and process the soil data and generate the final map sheet. (EVR/GB)

Harmonized World Soil Database

The soil maps presented in this atlas are primarily derived from the Harmonized World Soil Database (HWSD) that has been developed under the Land Use Change and Agriculture Program of the FAO and IIASA (Austria) in partnership with ISRIC – World Soil Information and the European Commission Joint Research Centre/European Soil Bureau Network [69].

The original HWSD data for Africa combines a number of existing regional and national sources of soil information such as SOTER and SOTWIS (Secondary SOTER databases) with the FAO-UNESCO Soil Map of the World [FAO/UNESCO 1971-1981]. The scale of the input data varies from 1:1 000 000 (for Eastern and Southern Africa, parts of the Mediterranean) to 1:5 000 000 (the Sahara, west Africa and most of central Africa).



The HWSD is composed of data from the Digital Soil Map of the World (DSMW) at a scale of 1:5 000 000 and the SOTWIS (Harmonized continental SOTER-derived database) programe at a scale of 1:1 000 000. The soil names used in the legend of the DSMW are referred to as FAO-74, which in turn was adapted to FAO-90 for the SOTER exercise. (JRC)

At these small scales, the location of individual soil types can not be delineated. Therefore, the database presents the locations of groups of soil types (also known as associations) that are referred to as a Soil Mapping Units or SMU for short. SMUs correspond to areas in the landscape where the same combination of soils are present, in the same position and have functioning relations between them. Individual soil types are referred to as Soil Typological Unit (STU). While the proportion of each STU within an SMU is specified, the location is not defined. Data on soil characteristics are assigned to STUs.

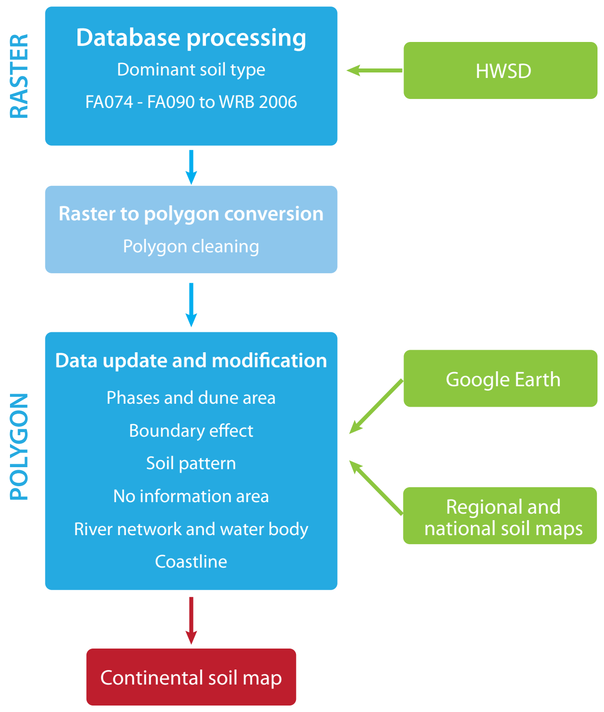
The HWSD is a raster or grid-cell database where the SMUs from the input soil datasets have been gridded to a resolution of 30 arc-seconds (nominally about 1 km). The pixel size was selected to ensure compatibility with important inventories such as the SRTM terrain data and the 2000/2005 global land cover datasets. The HWSD by necessity presents multiple grid cells with identical attributes reflecting the much coarser scale of the original vector data. For each SMU, the database records a standardised set of topsoil (0-30 cm) and subsoil (30-100 cm) characteristics of up to nine soil types (STU). These include:

- organic carbon;
- pH;
- water storage capacity;
- soil depth;
- cation exchange capacity;
- total exchangeable nutrients;
- lime and gypsum contents;
- sodicity and salinity;
- textural class;
- phase information;
- soil name.

The HWSD can be downloaded from the IIASA website: http://www.iiasa.ac.at/

Data processing

The various data processing stages required to produce the soil maps in the atlas are described below (JRC) [70].



Step 1. Assigning the dominant soil type

As each pixel or cell of the HWSD can contain up to nine individual soil types, a single soil type was selected as being representative of a particular SMU on the basis of the largest areal extent within the SMU. While it is clear that this approach masks the diversity of soil present within an SMU and presents a simplified view of soil distribution across Africa, the final map is much clearer. The reader should remember that the main goal of this publication is to introduce and highlight the diversity and importance of the soils of Africa to a new audience, outside of the soil science community. Specialists who need more detailed information can download the HWSD from the IIASA web site (see page 136).

Step 2. Translation to WRB

Within the HWSD, the name of the soil is given using either the legends of the 1:5 000 000 Digital Soil Map of the World (FAO-74) or SOTER (FAO-90). To harmonise these two systems and the existing JRC Soil Atlas series, these names were translated to the WRB scheme.

WRB_96		FAO_90		FAO_74	
	ACRISOLS				
ACfr	Ferric Acrisols	ACf	Ferric Acrisols	Af	Ferric Acrisols
ACgl	Gleyic Acrisols	ACg	Gleyic Acrisols		
ACha	Haplic Acrisols	ACh	Haplic Acrisols		
ACpl	Plinthic Acrisols	ACp	Plinthic Acrisols	Ap	Plinthic Acrisols
ACum	Umbric Acrisols	ACu	Humic Acrisols		
	ALISOLS				
ALgl	Gleyic Alisols	ALgl	Gleyic Alisols		
ALha	Haplic Alisols	ALha	Haplic Alisols		
ALpl	Plinthic Alisols	ALpl	Plinthic Alisols		
ALum	Umbric Alisols	ALum	Humic Alisols		
	ANDOSOLS				
ANsn	Silandic Andosols	ANh	Haplic Andosols	To	Ochric Andosols
ANsnmo	Silandic Mollic Andosols	ANm	Mollic Andosols	Tm	Mollic Andosols
ANsnum	Silandic Umbric Andosols	ANu	Umbric Andosols	Th	Umbric Andosols
ANvi	Vitric Andosols	ANz	Vitric Andosols	Tv	Vitric Andosols
	ARENOSOLS				
ARab	Albic Arenosols	ARa	Albic Arenosols		
ARbr	Brunic Arenosols	ARb	Cambic Arenosols	Qc	Cambic Arenosols
ARca	Calcaric Arenosols	ARc	Calcaric Arenosols		
ARfl	Ferralic Arenosols	ARo	Ferralic Arenosols	Qf	Ferralic Arenosols
ARha	Haplic Arenosols	ARh	Haplic Arenosols		
ARpr	Protic Arenosols				
ARwl	Hypoluvic Arenosols	ARl	Luvic Arenosols	Ql	Luvic Arenosols
	CALCISOLS				
CLha	Haplic Calcisols	CLh	Haplic Calcisols	Bk	Calcic Calcisols
CLhaye	Haplic Yermic Calcisols				
CLpt	Petric Calcisols	CLp	Petric Calcisols		
CLlv	Luvic Calcisols	CLl	Luvic Calcisols		
	CAMBISOLS				
CMca	Calcaric Cambisols	CMc	Calcaric Cambisols		
CMcr	Chromic Cambisols	CMx	Chromic Cambisols	Bc	Chromic Cambisols
CMdy	Dystric Cambisols	CMd	Dystric Cambisols	Bd	Dystric Cambisols
CMeu	Eutric Cambisols	CMe	Eutric Cambisols	Be	Eutric Cambisols
CMfl	Ferralic Cambisols	CMO	Ferralic Cambisols	Bf	Ferralic Cambisols
CMgl	Gleyic Cambisols	CMg	Gleyic Cambisols	Bg	Gleyic Cambisols
CMhaty	Haplic Takyric Cambisols				
CMhaye	Haplic Yermic Cambisols				
CMvr	Vetric Cambisols	CMvr	Vetric Cambisols	Bv	Vetric Cambisols

Example of the translation of HWSD soil names to WRB. (JRC)

Step 3. Conversion of raster database to polygons

At the conclusion of the soil name translation stage, the raster database was converted to polygons to facilitate the cartographic stage. Cells with adjacent soil names were merged in this process. 'Micro-polygons' which were too small to be labelled on the map were merged with adjacent polygons in order to produce 'clean' maps. These are indicated by the red speckle on the summary map below.

Step 4: Phase updates

As a result of a visual inspection of the database, a number of modifications were made to the original HWSD using the phase parameters.

Phases 3 and 6 were used to redefine the extent of Plinthosols in central and west Africa, which were previously absent (the green areas in the summary map).

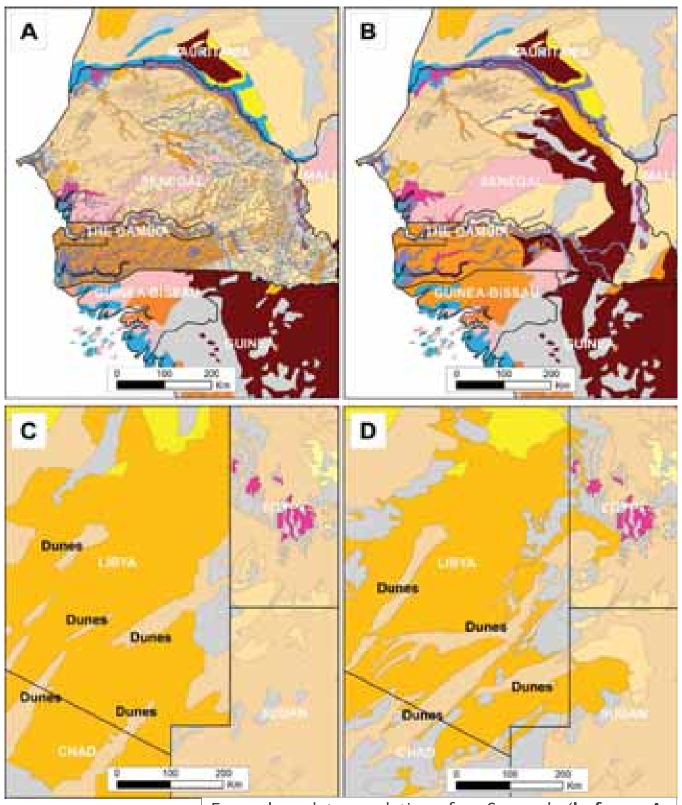
- Areas defined as 'dune sand' in FAO-74 and ARh in FAO-90 were converted to ARpr. Intensive checking of the data with Google Earth also allowed new dune areas to be detected and obvious misclassifications corrected (the yellow areas in the summary map).

At this stage, a decision was taken not to over-clean the SOTER data with respect to the coarser information from the original DSMW. While the preservation of detail at the expense of cartographic harmonisation may have produced some 'noisy' map sheets (see pages 112 – Kenya and 126 – South Africa), the Editorial Board felt that it was better to highlight the lack of data in other parts of the continent.

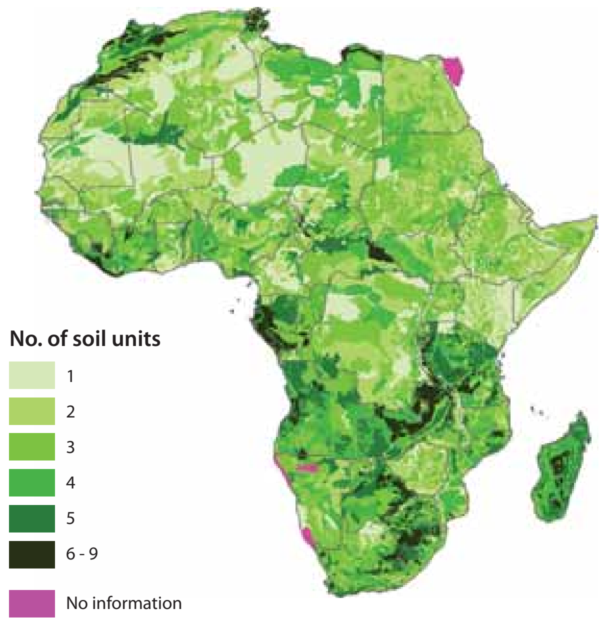
Step 5. Data updates and modifications.

Several major modifications were carried out to the initial data contained in the HWSD on the basis of expert knowledge and the publication of new data (unless otherwise stated, these changes are indicated as red areas on the summary map) :

- Boundary effects at the administrative borders of several countries were removed on the basis of expert knowledge;
- Soil patterns for several countries (e.g. Cameroon, Zambia, Malawi and Lesotho) were updated with more recent data;
- Harmonisation of the main river networks and water bodies;
- Grid cells without any data were assigned soil names from secondary data sources (e.g. Sinai Peninsula, coastal areas of Namibia) (black areas on the summary map);
- Modification of the coastline (e.g. the Nile Delta) – pink areas on the summary map.

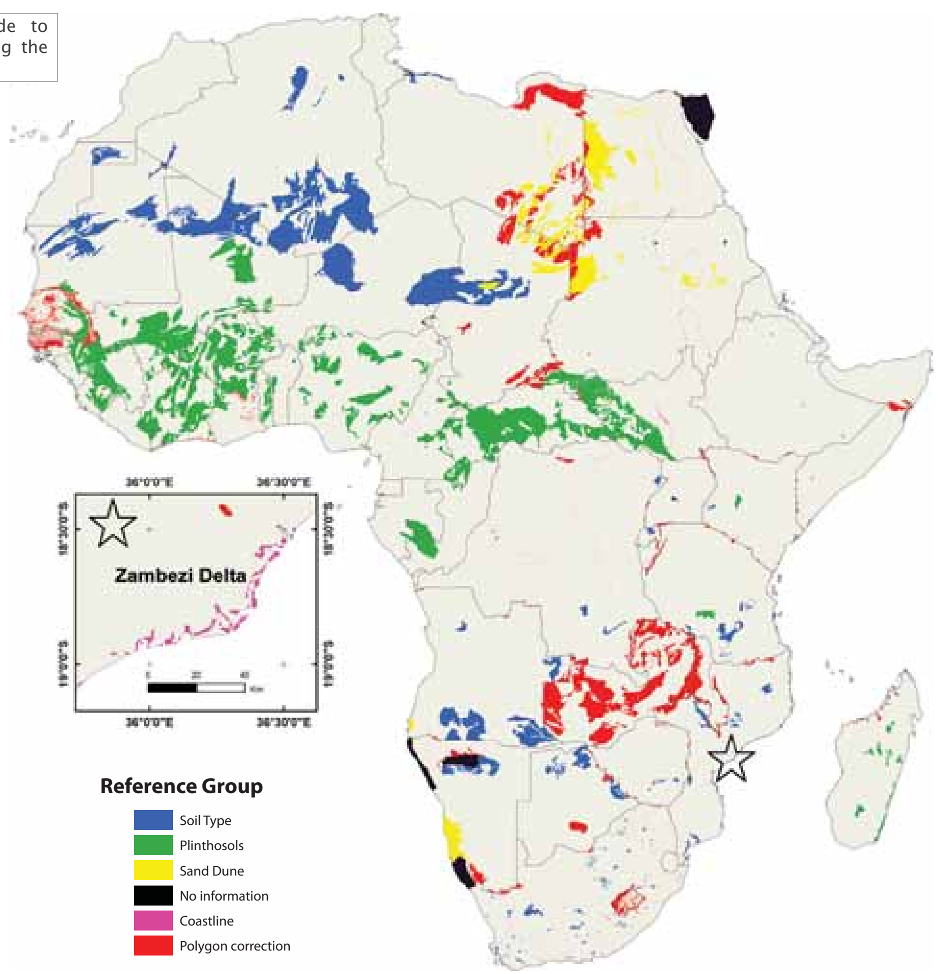


Examples data updating for Senegal (**before, A; after, B**) and boundary harmonisation on the Libyan – Egyptian – Sudan border (**before, C; after, D**). (JRC)



Map of soil diversity. The numbers in the legend indicate the numbers of soil types in an individual SMU. The higher the number, the more soil types in a SMU. Low values can reflect either the actual situation (e.g. desert areas may only have one or two soil types) or a limited amount of soil survey in the area (e.g. the Congo Basin). (JRC)

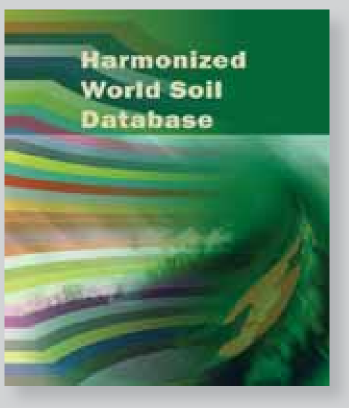
Map summarising the modifications made to the Harmonized World Soil Database during the production of the atlas. (JRC) [70]



HWSD

The Harmonized World Soil Database (HWSD) is freely available to download as a standalone database or together with a viewing application from:

http://www.iiasa.ac.at/



Additional sources of data on African soils

African Soil Information Service

Africa Soil Information Service
www.AfricaSoils.net

Because knowledge about the condition and trend of African soils is highly fragmented and dated, there is an urgent need for accurate, up-to-date, and spatially referenced soil information to support agriculture and associated environmental concerns in Africa. This coincides with developments in technologies that allow for accurate collection and prediction of soil properties.

In November 2008, an US$18 million grant was awarded to the GlobalSoilMap.Net consortium (see adjacent text) from the Bill & Melinda Gates Foundation and the Alliance for a Green Revolution in Africa (AGRA) to map the soils of Sub-Saharan Africa. This support has led to the development of the Africa Soil Information Service (AfSIS), a large-scale, research-based project that aims to develop a practical, timely, and cost-effective soil health surveillance service to map soil conditions, set a baseline for monitoring changes, develop global standards and methodologies, and provide options for improved soil and land management in Africa.

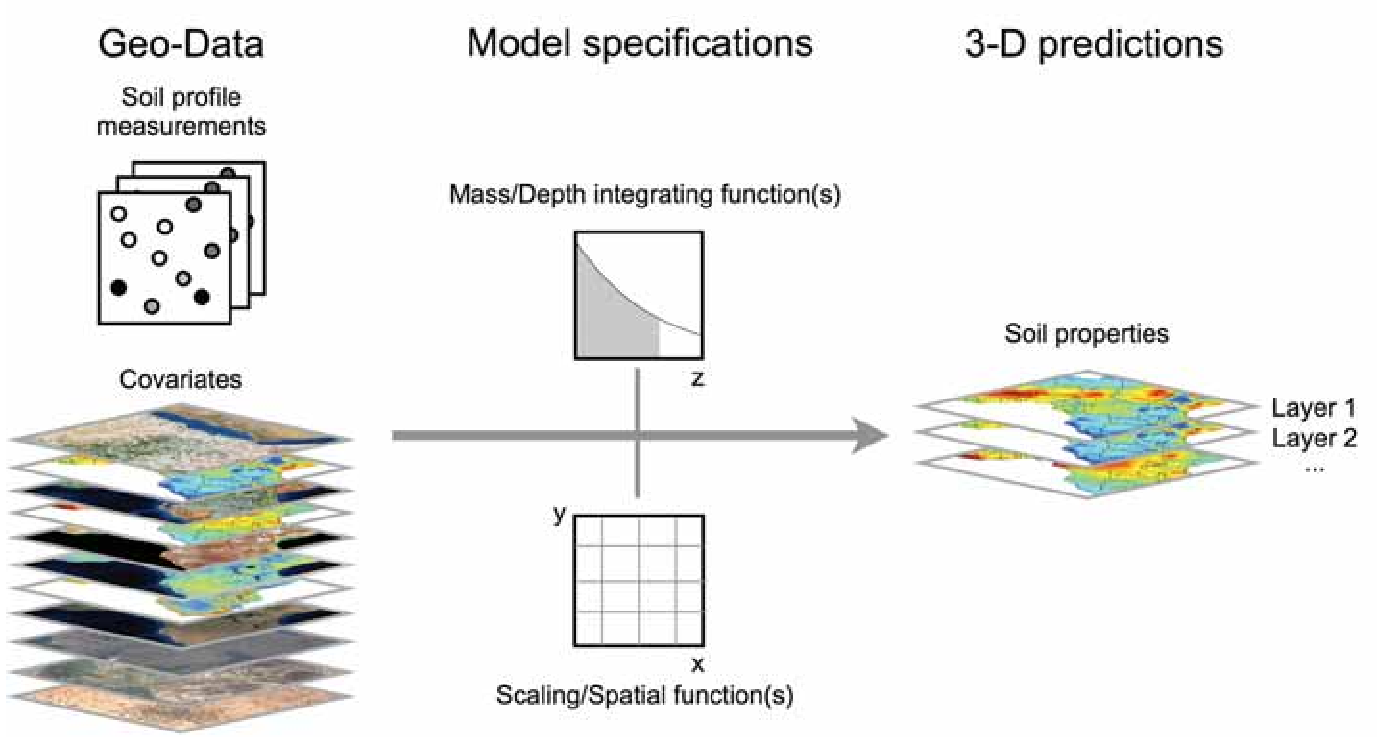
AfSIS is building on recent advances in digital soil mapping (see left) and integrated soil fertility management to improve the way that soils are evaluated, mapped and monitored, while significantly reducing the costs to do so.

AfSIS is producing digital soil maps that are fully compliant with the GlobalSoilMap.Net initiative using legacy data (e.g. ISRIC-WISE, SOTER databases), new soil data collection (Sentinel Sites), data from remote sensing systems (e.g. MODIS, Landsat and SRTM derivatives), together with a range of ancillary environmental datasets. The system is also facilitating the identification of areas at risk of soil degradation and corresponding preventive and rehabilitative soil management interventions based on analysis of what works and what does not.

Dissemination and training exercises are making the project's outcomes accessible to farm communities, public and private extension services, national agricultural research and soil survey organisations, the fertiliser sector, project and local planners, national and regional policy makers, and scientists. The efforts in Africa are part of a wider, global effort to digitally map the world's soil resources.

AfSIS is coordinated by the Tropical Soil Biology and Fertility Institute of the International Center for Tropical Agriculture (CIAT), located in Nairobi, Kenya. CIAT provides grants to the Tropical Agriculture and Rural Environment Program and the Center for International Earth Science Information Network (CIESIN) at the Earth Institute of Columbia University, the World Agro-Forestry Centre (ICRAF) and ISRIC - World Soil Information in the Netherlands.

For further information, please visit:
http://www.africasoils.net/home



A schematic representation of digital soil mapping. Soil conditions at known locations are combined with associated datasets (referred to as covariates) and used to seed statistical models that predict soil properties for unknown areas. A strength of digital soil mapping is the ability to produce maps rapidly, together with a quantitative assessment of accuracy. However, errors may occur if the model is unable to account fully for the parameter in question or if there are reliability issues with the input data. (AfSIS)

GlobalSoilMap.Net

GlobalSoilMap.Net is a global consortium that has been formed to produce a new digital soil map of the world using state-of-the-art and emerging technologies. This new dataset will use geo-statistical procedures to predict key soil properties at a spatial resolution of approximately 100 m (i.e. grid cells of 100 m x 100 m). Twelve soil properties will be calculated for each cell. These are: (1) total profile depth (cm), (2) plant exploitable (effective) soil depth (cm), (3) organic carbon (g/kg), (4) pH, (5) sand g/kg), (6) silt (g/kg), (7) clay (g/kg), (8) gravel (% volume), (9) ECEC (cmol^c/kg), (10) bulk density of the fine earth (< 2 mm) fraction (excluding gravel) (Mg/m^3), (11) bulk density of the whole soil (including gravel) and (12) available water capacity (mm). Additional soil properties (e.g. electrical conductivity) may also be predicted but these are not mandatory. In the vertical dimension, predictions of soil property values and their associated uncertainties will be reported for six depth intervals: 0-5 cm, 5-15 cm, 15-30 cm, 30-60 cm, 60-100 cm and 100-200 cm [71].

The project was officially launched on 17th February 2009 in New York, USA. The GlobalSoilMap.net consortium, which is led by ISRIC - World Soil Information (Wageningen, the Netherlands), includes the Joint Research Centre of the European Commission (Ispra, Italy), CSIRO (Canberra, Australia), the University of Sydney (Australia), Institute of Soil Science of the Chinese Academy of Sciences (Nanjing, China), the Earth Institute at Columbia University (New York, USA), the US Department of Agriculture Natural Resources Conservation Service (Morgantown, USA), the IRD (Montpellier, France), the Brazilian Agricultural Research Corporation Embrapa (Rio de Janeiro, Brazil) and CIAT-TSBF (Nairobi, Kenya).

For further information, please visit:
www.globalsoilmap.net

Digital Soil Mapping

The soil maps presented in this atlas are the result of traditional soil survey which involves the manual delineation of soil boundaries by soil scientists based on soil samples gathered in the field and an understanding of the relationship between landscape and parent material. However, such approaches are demanding in terms of human resources, cost and time.

In recent years, attention has focused on the possibilities offered by digital soil mapping (DSM), also referred to as predictive or pedometric mapping. DSM uses geo-statistical models to predict soil properties and degradation pressures at unobserved locations in the landscape in much shorter timeframes than conventional soil surveys [72].

As illustrated in the diagram above, a digital soil map is in simple terms a spatial database of soil properties. These properties are based on a statistical elaboration of a sample of known conditions at specific locations or regions that permits the interpolation or prediction of soil properties to unknown areas.

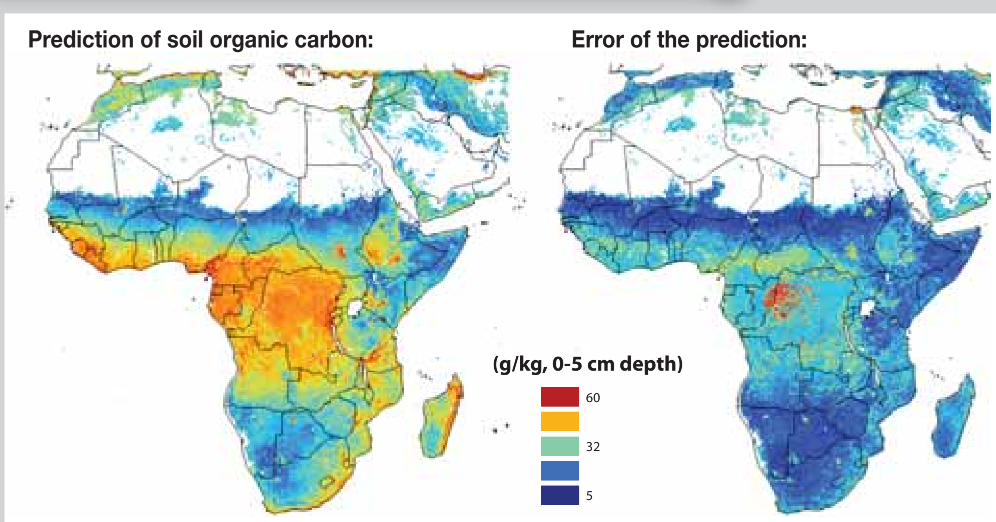
Soil characteristics can be predicted by a variety of statistical approaches which differ in terms of their representational realism and computational complexity. They include classic geo-statistics (e.g. regression kriging, co-simulation, etc.), as well as more recent approaches based on hierarchical models, generalised estimating equations, additive models, Markov Chain and Monte Carlo simulations among others.

The predictions are strongly driven by the relationship between soil conditions at known locations and associated datasets know as covariates. These include reflectance data and derived information from satellite images (e.g. albedo, land cover), digital terrain models and climatic conditions (e.g. soil moisture, annual temperature, etc.).

This approach essentially attempts to quantify Jenny's classical model of soil formation, which states that a soil condition is a function of a number of factors including climate, organisms, relief, parent material, age (or time) and any other, typically more local and historically significant factors. The basic hypothesis underpinning digital soil mapping is that once the spatial distribution of these factors is known, specific soil properties or conditions may be inferred geographically on the basis of their inter-relationship across the landscape.

A key aspect of DSM is the production of uncertainty statements which indicate the reliability of the predicted soil properties.

Predicting soil organic carbon content



The map on the left predicts the value of mean soil organic carbon (g/kg) for a 0-5 cm depth based on legacy data, global covariates and a geo-statistical procedure known as 3-dimensional (3D) regression kriging. The map on the right shows the standard error of the prediction. On this map, low values indicate low errors while there are greater uncertainties in predictions for the Nile Delta and the wetlands of the River Congo. The work was carried out as part of the AfSIS project. (TH)

ISRIC World Soil Information

ISRIC – World Soil Information

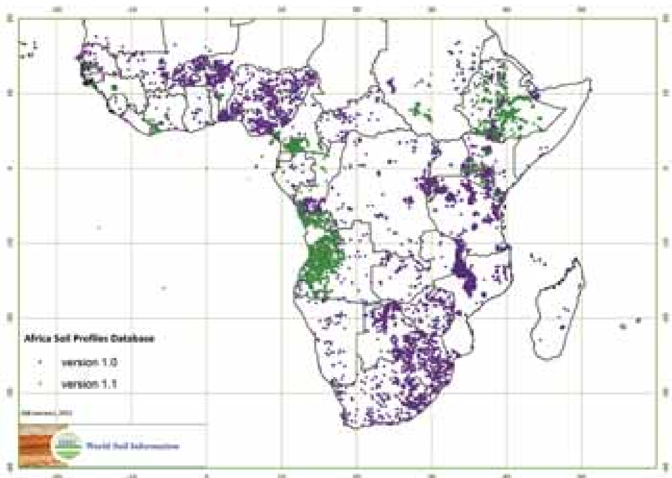
ISRIC - World Soil Information is an independent centre of excellence in soil science, established in 1966 with a mandate to serve the international community with information about the world's soils. In this context, ISRIC aims to:

- Inform and educate about the world's soils;
- Serve the scientific community as custodian of global soil information;
- Undertake applied research on land and water resources.

Located in Wageningen in the Netherlands, ISRIC is the World Data Centre for Soils (WDC-Soils) within the International Council for Science World Data System and also maintains the World Soil Museum and World Soil Library. Regarding the soils of Africa, ISRIC offers the following pertinent information sources:

- Africa Soil Profiles Database (see right);
- WISE-derived soil properties on a 5 x 5 arc-minutes global grid;
- Soil and Terrain Database for South Africa (1:1 million) and Central Africa (Democratic Republic of Congo 1:2 million, Burundi and Rwanda 1:1 million);
- SOTER-based soil parameter estimates for Southern Africa and Central Africa;
- ISRIC Scientific Reports;
- Archive of soil maps.

For further information, please visit:
http://www.isric.org/



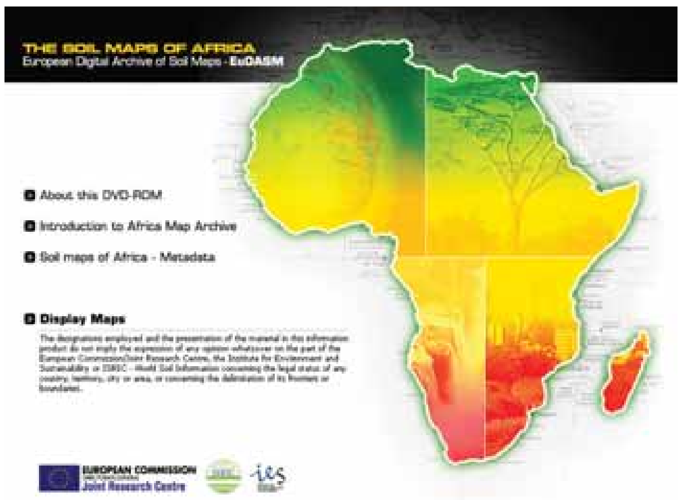
Africa Soil Profiles Database

ISRIC - World Soil Information is compiling a database of legacy soil profile data from Sub-Saharan Africa in support of the AfSIS project (see previous page).

The Africa Soil Profiles database (version. 1.1, March 2013) contains more than 16 500 unique soil profiles from a variety of data sources, nearly all of which are geo-referenced, with available soil layer attribute data. Soil analytical data are present for 12 600 geo-referenced profiles. The database contains, but is not limited to, the attributes specified by the GlobalSoilMap.net consortium.

Soil attribute values are standardised and quality controlled. Unusual values are flagged. The degree of validation and associated reliability of the data varies because reference soil profile data that are previously and thoroughly validated are compiled together with non-referenced soil profile data of lesser inherent representativeness [73]

For further information, please visit:
http://www.isric.org/data/africa-soil-profiles-database-version-01-1



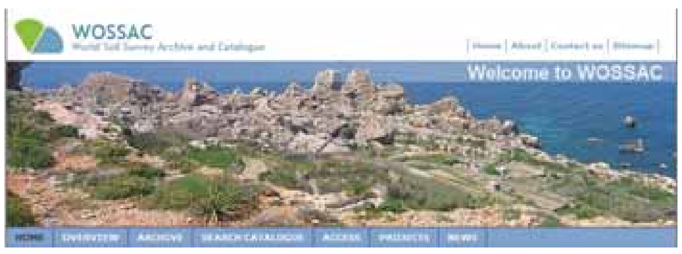
European Digital Archive of Soil Maps (EuDASM)

For nearly 50 years, ISRIC – World Soil Information has been collecting and archiving regional-, national- and global-scale maps of soils and land resources.

Despite effective procedures for storage and maintenance, most organisations involved in archiving struggle to prevent the deterioration of paper maps and the quality of information they contain. Deterioration occurs for various reasons that include handling, transport, exposure to light, moisture and atmospheric pollution.

Realising the need to conserve the information on existing maps, the European Commission and ISRIC – World Soil Information initiated the European Digital Archive of Soil Maps (EuDASM) to transfer paper soil information into a stable digital format, with the maximum resolution possible. More than 2 000 maps were scanned from the ISRIC Africa collection using a wide format colour scanner and stored at 200 dpi in JPEG compressed format. [67]

For further information, please visit:
http://eusoils.jrc.ec.europa.eu/esdb_archive/EuDASM/Africa/index.htm



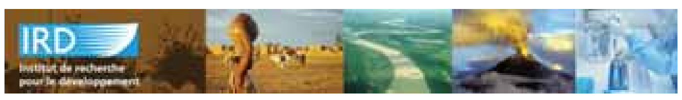
World Soil Survey Archive and Catalogue

Over the past 80 years, tens of thousands of substantial soil surveys have been undertaken across the world by British organisations, mainly funded by governments as well as development assistance donors. A rough estimate, almost certainly on the low side, is that such surveys by today's prices would cost many hundreds of millions of euros to repeat and in all likelihood, such surveys are unlikely to be undertaken again in the near future! Yet until recently, many of these unique materials were scattered, unprotected and in danger of being lost forever. It is in this context that the World Soil Survey Archive and Catalogue (WOSSAC) project aims to develop an archive and catalogue of all substantial soil surveys, reports and maps made by British companies and personnel. WOSSAC will provide a safe repository for endangered copies and make the accrued information available for consultation by interested parties.

The WOSSAC Archive is based at Cranfield University, UK. The archive itself comprises a soil reports section, a soil maps and albums section, a soil books section, an aerial photography section and a satellite imagery section.

Currently, the WOSSAC Archive holds many thousand items for around 280 countries and territories worldwide, of which 22 478 objects have been catalogued. Of the catalogued material, Sudan, Nigeria, Tanzania, Morocco and Zambia are the most represented African countries. Items are constantly being added.

For further information, please visit:
http://www.wosssac.com/



Institut de recherche pour le développement (IRD)

The IRD is a French research organisation that addresses international development issues throughout the world. Key objectives include the improvement of sanitary conditions and understanding the evolution of society while preserving the environment and natural resources.

As a French science and technology establishment, the IRD is under the joint supervision of the Ministries of Research and Foreign Affairs. It operates internationally from its headquarters in Marseille, and two centres in Montpellier and Bondy.

Thanks to its collaborative activities in research, education and innovation, IRD has been active in more than fifty countries, with particular focus on northern and western Africa.

Of particular interest to researchers interested in Africa are three online services:

Horizon – a document archive containing more than 80 000 reports with a full-text search facility available on 42 000 articles;

Sphaera cartographie – a comprehensive map archive containing 18 000 cartographic references and 2 700 digitised maps and atlases;

Indigo - IRD's image gallery containing more than 40 000 photographs.

For further information, please visit:
http://en.ird.fr/ (English)
http://www.ird.fr/ (French)

The FAO

For information on data and documents in relation to the soils of Africa at the UN Food and Agriculture Organization (FAO), see page 174.

UNIVERSITEIT GENT

Ghent University

The Laboratory for Soil Science at Ghent University is well known for its expertise in soil survey, soil classification and evaluation. It hosts an extensive collection of hardcopy soil maps as well as digital soil information systems of several African countries, which were acquired during field work and research projects in the past decades. The soil map of Rwanda is accessible online, and similar activities are planned for the soil maps of the DR of Congo.

For further information, please visit:

http://www.labsoilscience.ugent.be
http://www.labsoilscience.ugent.be/soilmaprwandaintro.html

Royal Museum for Central Africa

The Royal Museum for Central Africa (RMCA) in Tervuren, Belgium, holds a number of invaluable sources of information on the countries of central Africa and especially the DR Congo, Rwanda and Burundi. Many documents and maps are currently being digitised in order to make them accessible to researchers worldwide.

In addition, the Cartography Service stores satellite images of Africa acquired within the framework of research projects, aerial photographs acquired by or entrusted to the institution, photographs of Central Africa and geological and theme-based maps.

For further information, please visit:
http://www.africamuseum.be/

Soil across Africa

In general, the African continent may be divided into seven broad geographical regions. Each region is defined by distinct geological, climatic and/or ecological characteristics and landscapes which, in turn, determine the soil properties. Specific soil types are not necessarily exclusive to a region (i.e. Cambisols may occur in all regions while Gypsisols are only found in arid locations). However, broadly speaking each region can be characterised by a typical assemblage of soil types (e.g. wetlands and river valleys will contain more gleys, organic-rich and fluvial soils than other regions). In summary, the soil regions of Africa can be described as:

Mediterranean – found on the northern and southern margins of the continent. The climate is characterised by a dry, hot summer (> 35°C) and cooler winters (10°C), with rain fall only in the winter months. Vegetation tends to be shrubby but agriculture can be productive if water is readily available. Soil organic matter levels are generally low. Soil parent material tends to be rich in lime or gypsum.

Deserts – consisting of the Sahara, the Kalahari and the northern Kenya–Somalia region. In addition to high aridity, the desert region is characterised by high mean monthly temperatures and large daily temperature range (often greater than the annual range of the mean monthly temperature). As a consequence, vegetation cover is low or non-existent and soils are coarse-textured, shallow, rocky or gravelly. Finer particles can be blown away leaving heavier fragments behind.

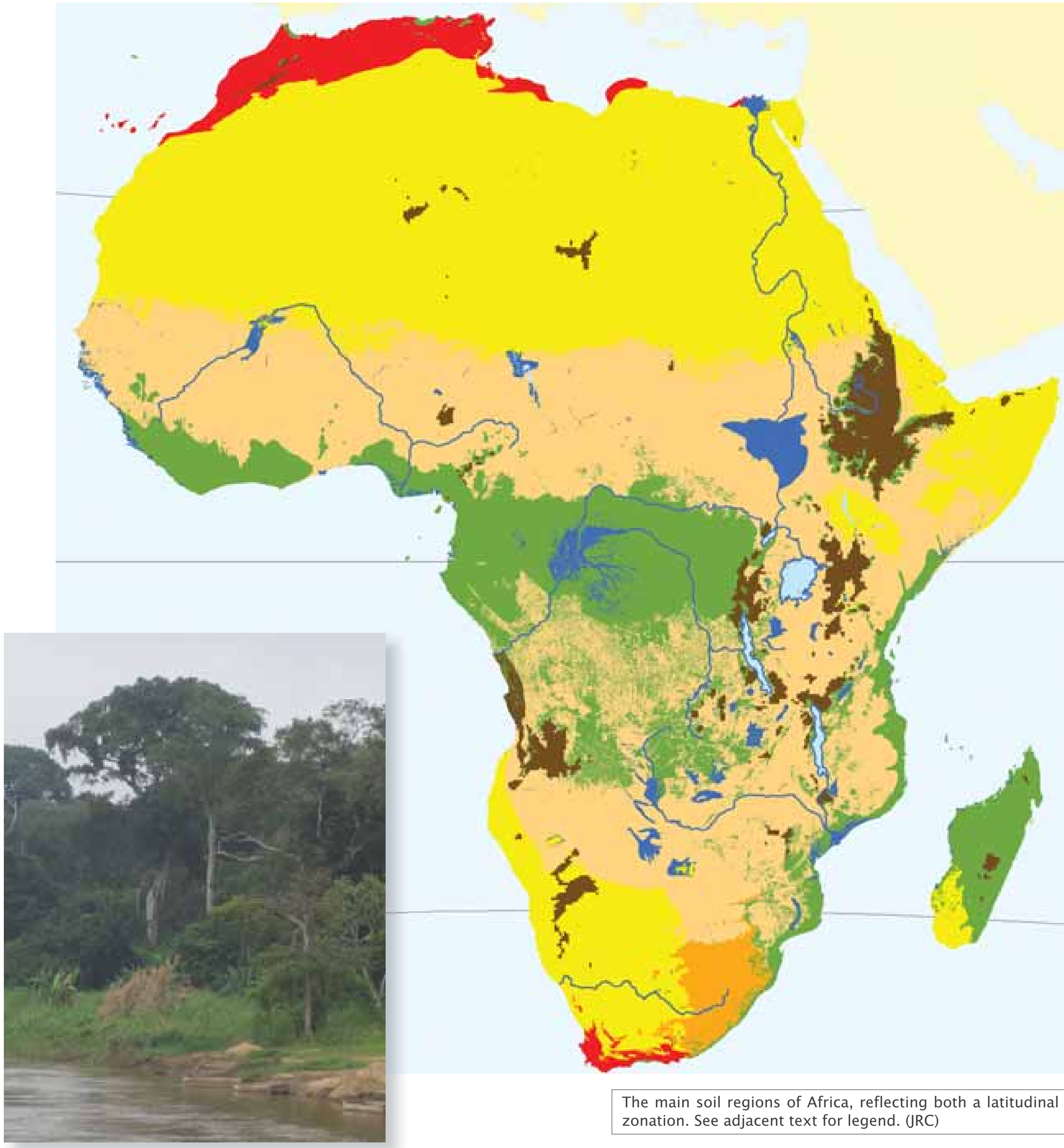
Sahel and Savannah – covering almost half of the total surface area of the continent, the savannah is a mixed grassland/ woodland ecosystem that is adjacent to the forest region. The soils are generally well drained and posses a thin layer of organic matter, which can be thicker in wetter conditions. They can support limited cultivation but can quickly become impoverished. Savannah regions often receive large quantities of sand and dust from adjacent drier regions.

Forests – tropical forests are characterised by high-levels of vegetation and the lack of seasonality (temperature is constant and conditions are either rainy or dry). Soils are generally nutrient-poor and acidic. Decomposition of organic matter is rapid and soils are subject to heavy leaching. Variations in climatic conditions cause a variation in the species composition and structure of the forest and consequently affect soil characteristics.

Mountains – the mountains of Africa fall into two broad types. The Atlas Mountains of North Africa, together with the highlands of the Sahara and South Africa, are hot and dry with limited soil development. In the rift region of eastern Africa and the highlands of Ethiopia, bio-climatic zones are defined by altitude. Soils can be varied and reflect the underlying geology. On the highest peaks, such as Kilimanjaro or the Ruwenzori Range, permanent snow can be found on the summits.

River valleys and wetlands – the soils on the floodplains of the major river valleys are characterised by stratified fluvial deposits, good drainage and high nutrient levels. Swamps are forested wetlands, similar to marshes, often found near rivers or lakes consisting of mineral soils that drain very slowly. Waterlogged conditions can result in the formation of peat. Mangrove soils occur in recent marine or river-borne sediments. Soils have high clay and silt content and contain high levels of organic matter.

Southern Africa – while not a specific biome as the others, the southernmost region of the African continent is characterised by a very old geology and a warm and dry climate which gives rise to some unique soil types. Overall, soils are generally thin and moderately fertile.



The main soil regions of Africa, reflecting both a latitudinal and altitudinal zonation. See adjacent text for legend. (JRC)

Characteristic landscapes of the seven main soil regions of Africa. Map Inset – rain forest from Cameroon (RJ); Clockwise from top left: wheat cultivation and olive trees in Morocco (EM); sand dunes in the Libyan part of the Sahara Desert (BN); savannah landscapes support large concentrations of grazing animals (EM); the Karoo National Park in South Africa (PLR); the wetlands of the Okovango Delta and sand dunes of the Kalahari are clearly visible from space (NASA); forested mountains in Tanzania with shallow Regosols in the foreground (EM).

Soil of Mediterranean Africa

So-called Mediterranean conditions occur on the northern (from Morocco to Egypt) and southern (from West Coast Peninsula to Port Elizabeth) coasts of the continent. The northern region falls into two distinct areas; one from Morocco to Tunisia, where the Atlas and Rif mountains dominate the landscape, and one comprising the Libyan and Egyptian coastline, where the Sahara almost reaches the sea. The southern region lies between the coast and the high plateau lands of South Africa. This region is characterised by mild, moist winters and hot, dry summers. Annual rainfall decreases along the Mediterranean coast from west to east, from about 950 mm in Tangiers to about 100-200 mm along the Egyptian coast. In the southern hemisphere, both Cape Town and Port Elizabeth receive around 650 mm but rainfall becomes more evenly distributed throughout the year to the east. Wind storms occur frequently in both regions. The naming of the Cape of Good Hope reflects this condition while the sirocco sweeps Saharan dust deep into Europe.

A large plume of dust (light-yellow haze) blowing northward off the coast of Libya and covering much of the Mediterranean Sea. Tunisia's northeastern coastline is visible on the left edge while the Italian island of Sicily appears in the upper left. This true-color image was acquired by NASA's MODIS sensor in the autumn of 2003. (NASA)

Historical events have left their imprint on the environment and soils of North Africa. Native vegetation has almost disappeared as a result of large-scale deforestation during Roman times (which led to wide-spread soil erosion) and the introduction of sheep and goats by the Arabs. In addition, over-exploitation of the water resources has resulted in salinisation of soils in many locations. Large areas have been converted to cropland with some replanted forests along the coast. Where crops cannot be grown due to climate or topography, sparse grassland can be found which is used for extensive grazing. Morocco and Tunisia are amongst the largest producers of phosphate in the world – a key component of inorganic fertiliser. The famous Fynbos biome of shrubland and thicket can be found in the southern hemisphere, which also contains much of South Africa's wine production.

In summary, the soils of this region are varied but generally low in organic matter and the presence of salts is common. They range from very sandy Arenosols in dune complexes to clay-rich Luvisols and Vertisols in level terrain. Where higher levels of rainfall occur, increased vegetation can give rise to Kastanozems in Morocco and leached Podzols in South Africa. Saline groundwater is responsible for Solonchaks while calcium carbonate is common along the Mediterranean coast.

Remnants of a Roman temple in Volubilis, Morocco. (OS)

Vineyards in Western Cape Province, South Africa. (EM)

Arenosol in old dune sand deposit northeast of Rabat, Morocco. (OS)

Vertisol from Morocco. Note the dark colour of the soil and the presence of deep cracks and smooth slickensides. The white material at the base of the profile is redeposited calcium carbonate. (OS)

Kastanozem from Morocco. The darker topsoil (0 – 40 cm) contains significant amounts of organic matter. The lighter material in the subsoil is calcium carbonate. (EM)

A Solonetz from South Africa; the columnar structure with rounded caps covered by dark coatings comprising clay and organic matter is typical of these soils. (ISRIC)

A red (chromic) Luvisol from South Africa. Luvisols display clay accumulations in the subsoil. (EM)

Soil of the deserts

Africa has two main desert regions: the Sahara in the north, stretching from the Atlantic Ocean to the Red Sea and the Horn of Africa; and the Namib and Kalahari deserts in the south, occupying a zone along the coast of Namibia and South Africa.

The Sahara is the largest hot desert in the world, covering about 9.5 million km^2. About 70% of the area consists of rock plateaus and rock-covered plains (hamadas or regs) while 30% is occupied by sand or dunes (called ergs). Rainfall is erratic and daytime temperature during the summer can reach over 50°C, while at night it can freeze.

Rock plateaus, escarpments and alluvial fans in the Niger Sahara with very little sand cover as seen by the Advanced Land Imager (ALI) on NASA's Earth Observing-1 satellite. There is very little sand in this part of the desert and a dry river bed or wadi cuts through the dissected landscape. (NASA)

The Sahara has not always been as dry and barren as it is today. Rock paintings showing giraffes, elephants, crocodiles and other animals indicate that a more lush vegetation and abundant water must have been present in the past.

Rock carvings of dancing cats (or perhaps dogs or even baboons!) from the Wadi Mathandush in central Libya. Such items illustrate the dramatic changes in climates that have affected the Sahara. (TS)

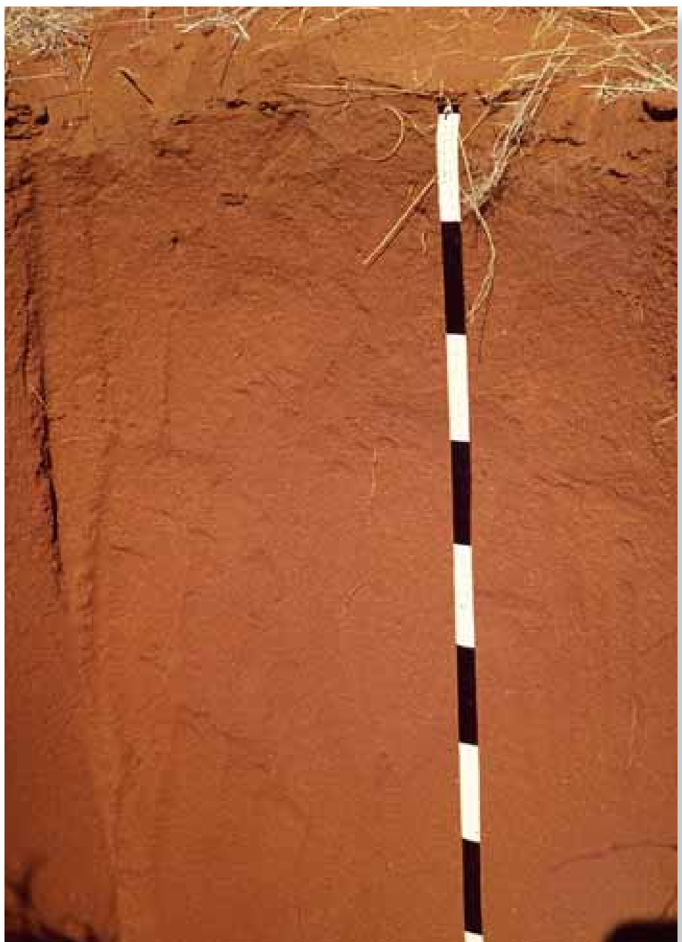
The Namib is regarded as the oldest desert on Earth (with an estimated age of 55 million years) and covers an area of about 81 000 km^2. It is also one of the driest places on Earth, with less than 10 mm rainfall annually. The few plants that can survive, amongst them Namibia's famous *Welwitscha*, draw moisture from the frequent fogs that drift inland from the sea. The southern part is mainly a sand desert with spectacular dune formations, the northern part is rocky and flat.

Large dune complex in the south of the Namib desert. (EM)

A variety of soils have been recognised in desert regions. Rock outcrops, gravelly deposits and sands constitute the largest part of soils in the deserts; these are Leptosols (referred to as Nudilithic when bare, Lithic when covered with a thin soil or deposit, and Hyperskeletic when consisting of thick rock debris). Sands are classified as Arenosols (Protic if non-stabilised, Haplic when stabilised, Rubic when reddish coloured). Many soils have notable secondary accumulations of salts (e.g. Calcisols, Gypsisols and Solonchaks) while abundant Regosols reflect the limited horizon development. In oases, Anthrosols may occur as a result of sedimentation through irrigation, whereas the dry river beds or wadis have Fluvisols.

A flooded salt flat in the Danakil Depression in Ethiopia. Saline water floods the area in the rainy season. Upon drying, the surface develops polygonal patterns through the horizontal expansion of salt crystals. The hill on the lefthand side is a salt mountain (diapir) resulting from a the upward thrust of the expanding salts. (RA)

An exposure of massive gypcrete that developed from the evaporite sediments of Lake Megafazzan, a giant lake that has existed in the Libyan Desert. Most Gypsisols are perceived as relicts of past environments and climates. (TS)



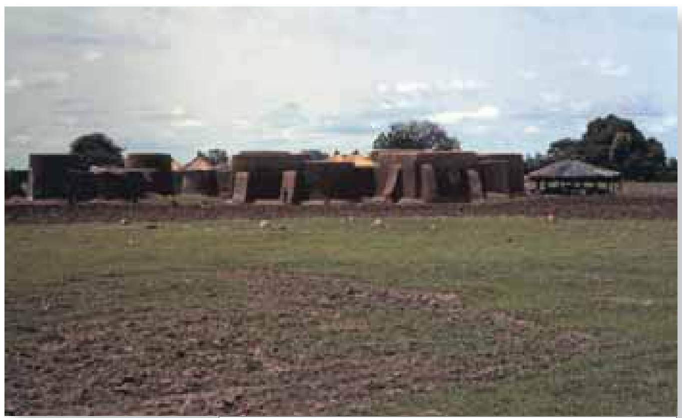
Red Arenosol from Namibia. The strong colour is caused by thin iron coatings on the sand grains. (ISRIC)

Gypsisol from the Kalahari desert in South Africa. (EM)

Gypsisol from Somalia. (RV)

Soil of the Sahel and Savannah

The Sahel and Savannah regions of Africa are bordered on one side by the deserts, by deciduous forest and tropical rainforest region on another and by the mountains and highlands on a third side. Characteristically they have one or two pronounced dry seasons of several months. Rainfall varies from 300 -1 000 mm per year. Their vegetation is open, ranging from sparse grassland to open-wooded grassland.



A village in the north of Ghana. Only land around dwellings is cultivated. (OS)

The Sahel and Savannah region is the most populated part of Africa. Most people live in small villages and their main source of income is agriculture. Depending on the amount of rain, food crops such as sorghum, maize, sweet potato, cassava, yam and a range of vegetables are grown. In many places the traditional slash-and-burn technique is practised. Cotton and tobacco are the most important cash crops. Attempts to grow wheat have failed, mostly because of the adverse soil conditions and diseases. Cattle and poultry farming are important. Drought is a major factor in agricultural production in this region.

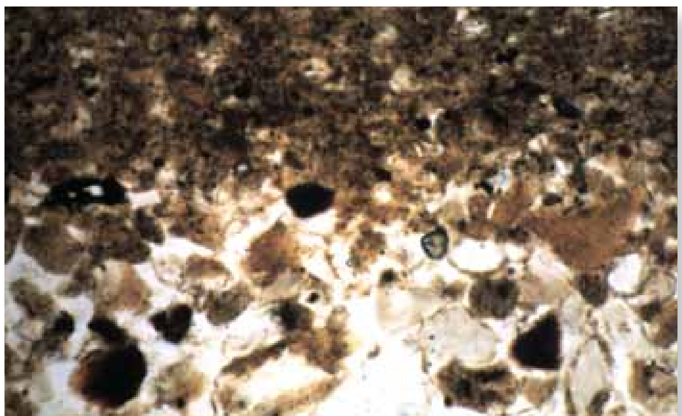
Slash-and-burn agriculture in Senegal. (OS)

The soils in this region are characterised by moderate leaching and, when adjacent to desert regions, by the addition of airborne dust. Most soils are old and deep, with a low nutrient-retention capacity because they are dominated by a kaolinitic clay mineralogy. Exceptions are the large level areas where shrink-swell clays are found; here the dominant mineralogy is montmorillonitic, resulting in a high nutrient-retention capacity. In general, the soils are poor in organic matter. The low leaching also results in the accumulation of carbonates if a source of calcium is present. Carbonates are also deposited as wind-blown dust (e.g. in the Harmattan regions). Many soils are red in colour due of the accumulation of hematite (iron oxide). The dominant soil types are Arenosols, Cambisols, Lixisols, Planosols, Plinthosols, Regosols, Solonetz and Vertisols.

A savannah landscape from the Congo. (EK/IRD)

Above: A red Lixisol from northern Ghana; A dark topsoil overlies a somewhat paler layer from which clay has been moved to the redder subsoil. (OS);

Below: Farmers cultivate Lixisols by scraping together the topsoil, the part of the soil with most fertility. (OS)



Harmattan dust as viewed through a microscope. The larger shapes in the lower half of the image are quartz grains of an Arenosol from Burkina Faso. The darker, upper half of the photograph is made up of much finer dust that has been deposited on top of the sand during a Harmattan event - note the difference in grain size. (ISRIC)

Truck on a temporary road over Planosols in central Ghana. The silty topsoil has no cohesion. Wheels leave deep spurs in the soil and the individual particles are swirled in the air by the truck to be blown away over hundreds of metres in the surrounding area. When wet, cars can easily sink in the mud up to their axles. (OS)

A termite mound in an Acrisol in Tanzania. Note the spacing between the larger bushes and trees. The open canopy allows sufficient light to reach the ground to support an unbroken herbaceous layer consisting primarily of grasses. Soil fertility is generally rather low in savannahs but may show marked small-scale variations. Trees can play a significant role in drawing mineral nutrients up from deeper layers of the soil while decomposing litter may also lead to high organic matter in the vicinity of trees. (EM)

A cultivated Vertisol that has developed on a very crystalline, intrusive igneous rock (pegmatite) in the savannah of central Burkina Faso. (MB/IRD)

Black Vertisol from the Abu Naana area in Sudan with a typical crumbly surface. (PB)

Soil of the forests

Dense tropical rain forests cover the coastal zone of West Africa from Guinea to Nigeria (with a short break in East Ghana and Benin), the southern parts of Cameroon, Chad and Central African Republic, and large parts of Gabon, Congo and DR Congo. In East Africa they are found in northern Mozambique and southern Tanzania, and along the east coast of Madagascar.

Dense tropical forest rises up on the banks of the Bodingué River in the Mbaéré-Bodingué National Park in the Central African Republic. (HG/IRD)

The climate is characterised by high temperature, high humidity and high rainfall all year round, although short dry spells do occur. Average temperature ranges from about 20 to 30°C with little fluctuation over the year and between day and night. Relative humidity is usually 90% or higher. Annual rainfall varies from 1 500 mm in the drier parts of the forest zone to about 10 000 mm along the western slopes of Mount Cameroon, the wettest part of Africa.

Tropical rain storm over central Congo. (OS)

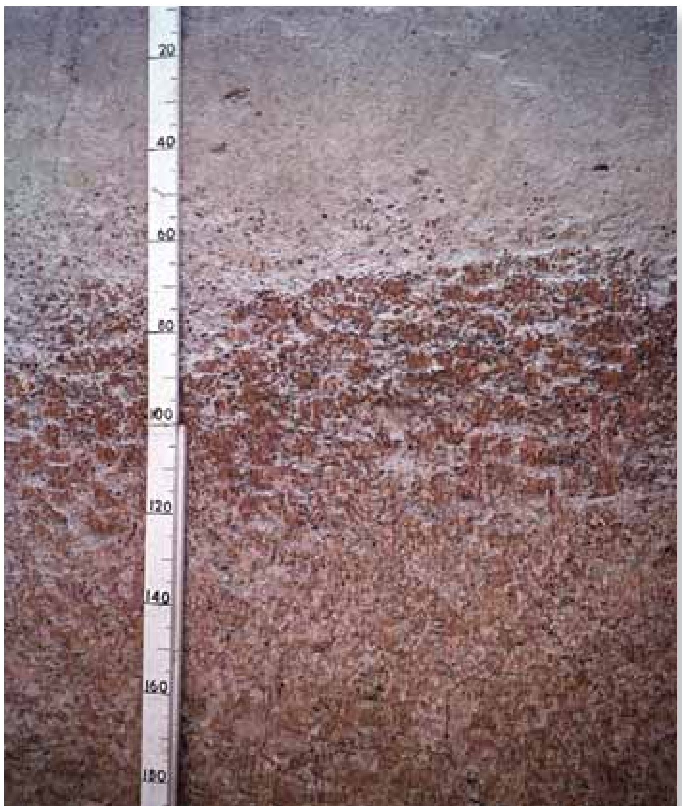
As in other parts of the world, the tropical rain forest in Africa is under pressure. Logging, expansion of cities and infrastructure, industrial activities and mining, development of large plantations (e.g. cacao, oil palm and rubber), and shorter fallow periods after cultivation are the main reasons for the disappearance of virgin forest. Only in the Democratic Republic of Congo do large tracts of original rain forest remain.

The soils of the upland forests in Africa are highly weathered, often deep and generally infertile. Due to the high rainfall and high temperature, the chemical alteration of primary rock constituents is rapid, leaving behind insoluble residues such as silica, iron and aluminium compounds. The resulting soil is often a mixture of quartz, the clay mineral kaolinite, goethite (iron-hydroxide) and sometimes gibbsite (aluminium-hydroxide). Most nutrients that are essential for plant growth (e.g. potassium, phosphorus) have disappeared. Large trees in the forest usually have a tap-root extending deep into the soil to take up nutrients from the weathering rock. Other plants live from the litter layer on the forest floor and the thin humus-rich topsoil.

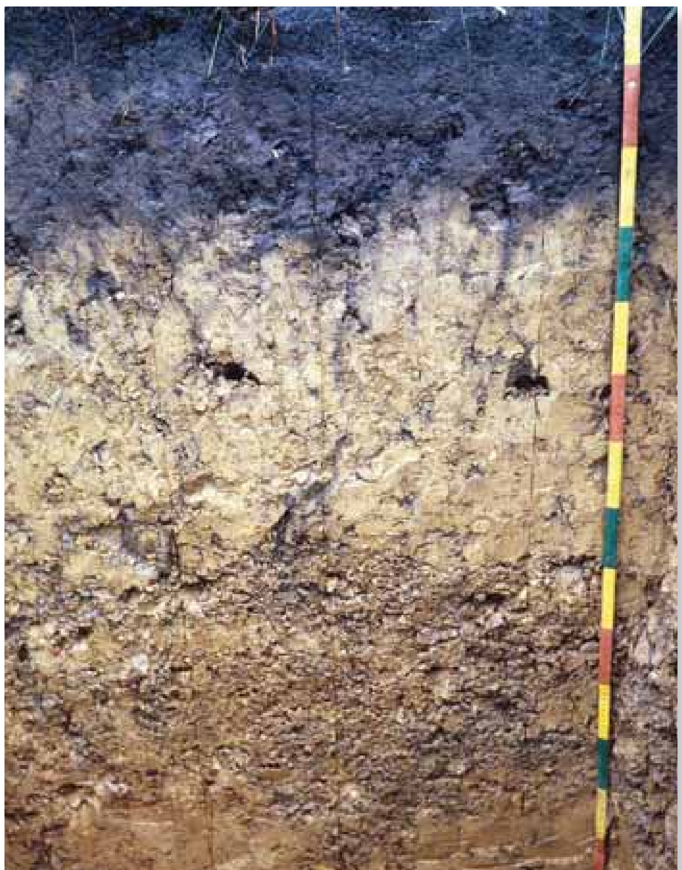
Ferralsols and Acrisols are common in well-drained positions with Plinthosols and Gleysols where drainage is poorer. Outcrops of basic rocks rich in iron may give rise to the formation of Nitisols.

Moist evergreen Afromontane forest in the Belete-Gera National Forest Priority Area, Oromia, Ethiopia. Farmers manage plots as 'coffee forests', a traditional, low-impact coffee production system where arabica coffee berries are collected from wild coffee shrubs. (RA)

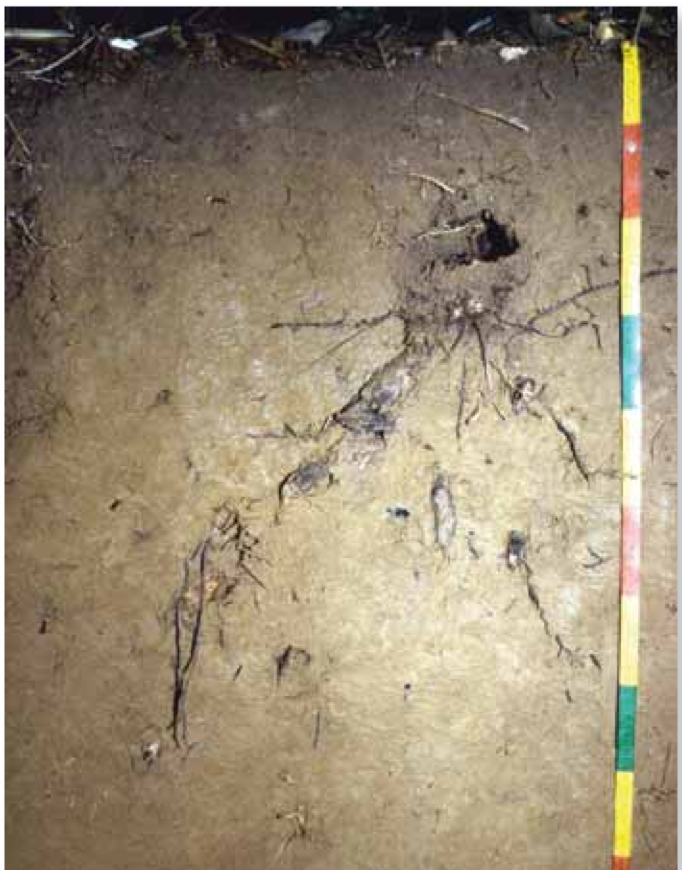
Ferralsol with a dark, humus-enriched topsoil over a uniform, yellowish subsoil from Gabon. The yellowish colour indicates the presence of goethite. (ISRIC)



Plinthosol from Ghana; a greyish layer abruptly overlies a layer rich in iron, which hardens irreversibly to "ironstone" when exposed to air and sunlight. When soft this material is called "plinthite". (ISRIC)



Acrisol from Gabon with a thick, black, humus-rich topsoil over a greyish, clay-enriched subsoil which becomes more red towards the sandstone rock from which the soil is derived. (ISRIC)



Gleysol from a forested valley in the Taï National Park of Côte d'Ivoire. (ISRIC)

Soils of mountains and highlands

The mountains and highlands of Africa occur in the extreme north-west (Atlas and Rif mountains), in its eastern part (Ethiopian highlands, the Ruwenzori range in Uganda and the Democratic Republic of Congo and the mountains of Kenya, Rwanda and Burundi), in central Africa (Cameroon and Angola), in the south-east (Drakensberg mountains in South Africa and the eastern highlands of Madagascar) and in isolated positions such as the Tibesti plateau in the central Sahara. The eastern highlands and mountains are related to the uplift action around the Rift Valley, which traverses Africa from Ethiopia to central Zambia. The Rif and Atlas mountains form part of the Alpine mountain building process. The others are remnants of earlier tectonic activity or are related to volcanism (e.g. Mount Cameroon). Some of the mountain peaks reach so high that permanent snow covers the top (e.g. Kilimanjaro, Ruwenzori), although much has disappeared during the past decades due to climate change.

Cultivation systems on Andosols in the volcanic highlands of Madagascar. (MB/IRD)

The summit of snow-capped Kilimanjaro on the border between Kenya and Tanzania in the late 1980s. (OS)

The highlands, particularly in east Africa, are densely populated areas. For example, the average size of land per household in Rwanda is about 0.2 ha. People are attracted to the highlands because of the mild climate, fertile soil and the wide range of crops that can be grown there (including cash crops such as tea and coffee).

Young tephra deposits in volcanic ranges give rise to Regosols, or Andosols in more weathered volcanic ash. Over time, these soils can develop into Luvisols, Nitisols, Lixisols and Acrisols, and, ultimately, into Ferralsols. The profile shows a young Andosol in the highlands of Kenya. The soil is built-up from several volcanic eruptions, which are recognisable from the different colours of the various volcanic ash layers. (EM)

Ferralsol from the highlands in Rwanda. The darker coloured layer in the centre of the picture is a so-called sombric horizon. Latest research suggests that this layer is a remnant of a deep, dark-coloured surface layer formed under grassland, of which the upper part has disappeared after forest took over (pers. comm. B. Delvaux). (ISRIC)

Intensive land use in central Rwanda where many tea and coffee plantations can be found. (OS)

The mountainous regions of Africa are dominated by shallow and weakly developed soils. Where mountains are steep, or where the climate is dry, such as in the Atlas and Rif mountains in the north-west and the Tibesti plateau in the Sahara, Leptosols and Regosols prevail. Under more humid climatic conditions or in less steep parts Cambisols develop, locally even Alisols or Acrisols. Due to more undulating topography, the soils of the highlands are generally much deeper than in the mountainous regions. The most common soils are Acrisols, Andosols, Ferralsols, Lixisols, Luvisols, Nitisols and Phaeozems. Vertisols occur on valley floors with Cambisols and Regosols on the steeper slopes.

Deep Nitisol profile from Tanzania showing a lack of strong horizon development due to a homogenisation of the upper part of the soil by biological activity. Nitisols show a characteristic blocky aggregate or 'nutty' structure. Nitisols are possibly the most inherently fertile of tropical soils due to their high nutrient content and deep, permeable structure. They are widely exploited for plantation agriculture. (MK)

Phaeozem under grassland in recent volcanic deposits, Kenya. A buried soil occurs below 120 cm depth. (ISRIC)

Soils of wetlands and river valleys

Wetlands in Africa are found along the coast in estuaries and deltas, as well as in inland areas. Well-known coastal wetlands are the Casamance Region in Senegal, the Niger Delta in Nigeria, the tidal flats near Douala, Cameroon and the Nile Delta in Egypt. Famous inland wetlands are the inner delta of the Niger River in Niger and the Okavango Delta in Botswana, the Etosha Pan in Namibia, the Zambezi floodplain and the Kafue Flats of Zambia, the Sudd along the Mountain Nile in South Sudan and the confluence of the Upper and Lower Congo Rivers in the Democratic Republic of Congo. Wetlands also occur on low-lying watersheds such as between the Zambezi and Kafue Rivers in Zambia.

The green area is the Inland Niger Delta. Fed by floodwaters from the Niger, Bani and a myriad of smaller rivers, the delta covers some 20 000 km² during the four-month rainy season that begins each July. During the dry season, the delta shrinks by roughly 80%. (NASA)

Wetlands play an important role in Africa. Many of them have a large variety of wildlife, which is attractive to tourists; hence, a number of wetlands are declared national parks. Some wetlands feature unique species, not to be found elsewhere in Africa, such as several Lechwes in Zambia, or the small wetland forest elephant in the Democratic Republic of Congo.

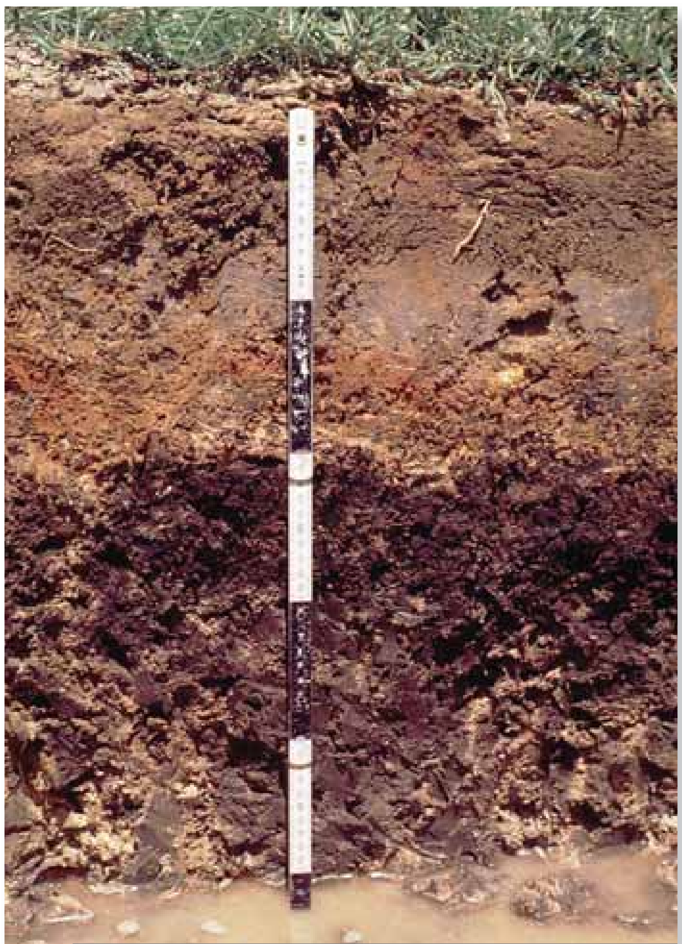
Black Lechwe, only to be found in the Bangweulu swamps of northern Zambia. (OS)

Some wetlands, such as in the inner delta of the Niger River and in the Nile Delta, provide sufficient water for irrigation, turning these regions into large agricultural areas. Other wetlands are used by local communities for fishing, which provides a major source for protein. Wetland vegetation varies from the submerged forests of the Congo Basin to salty grasslands in the Okavango Delta and the Etosha pan to mangrove forests in the Casamance. Seasonal floods in wetlands sometimes force people to move temporarily to higher grounds.

The soils of the wetlands and river valleys are all strongly influenced by water. The periodic or permanent wetness manifests itself as pale colours, strong mottling, sometimes giving rise to plinthite and, in the presence of saline water, salt accumulation. The most common soils are Fluvisols, Gleysols, Histosols, Planosols, Plinthosols, Solonchaks and Vertisols, and gleyic or histic variants of other types of soil.

The royal barge of the king of the Lozi people on its way over the flooded Zambezi floodplain. Soils on fluvial sediments can be found in all climatic and ecozones across Africa. Soils characteristics reflect the depositional environment. Coarse textured soils are indicative of flowing water while fine grained clays and silts (e.g. Vertisols) denote still water conditions. (K)

The red mottling below 50 cm is indicative of a soil that is affected by periodic waterlogging. The topsoil has been cultivated and does not show any features due to mixing. (EM)



Thionic Fluvisol (also known as acid sulphate soil) in the Senegal River Delta near Saint Louis. Acid sulphate soils contain high amounts of iron sulphates and are formed under waterlogged conditions, often in marine muds and sands of coastal wetlands. When exposed to air (e.g. due to drainage), they produce sulphuric acid that releases large and toxic quantities of iron, aluminium and heavy metals. (JD)

Mangrove vegetation along the Senegal River. Such soils are an important carbon sink and are often described as having tidalic characteristics. (JD)

Soils consistently saturated by groundwater (Gleysols) develop a characteristic greyish/blue colour pattern as a result of the lack of oxygen in the soil. (CVH)

Bog soil (Histosol) in the Kisanga Valley, Democratic Republic of Congo. (ISRIC)

The Etosha Pan, a saline wetland in northern Namibia. During the dry season the lake occupying the centre of the pan retracts, leaving a salt crust at the surface. (OS)

Soils of southern Africa

Although not a bio-climatic region as those described in the preceding pages, the soils of southern Africa deserve a special mention. This region, which includes roughly South Africa, Lesotho, Swaziland, a large part of Mozambique, Zimbabwe, Namibia, and the southern parts of Angola and Zambia, is underlain by a some of the oldest rocks on Earth - varying in age from 1 billion to 3.4 billion years. Granite, gneiss, migmatite, greenstone belts, volcanic intrusions and sedimentary rocks such as turbidites, greywackes, shales, sandstones and conglomerates form the main lithological constituents. The whole complex is of great economic importance; containing gold, diamonds, iron, platinum, chromium, titanium, uranium and tin ores. An important geological formation in the region is the Upper Pleistocene Kalahari Sand; with an area of 2.5 million ha it is the largest terrestrial sand body on Earth. It occurs in Botswana, western Zimbabwe, and the south of Angola and Zambia; outliers even reach the southern part of the Democratic Republic of Congo.

The climate is typically subtropical bi-modal with a rainy season starting around October/November and lasting until March/April. Temperatures are between 20°C and 25°C during daytime, dropping to around 15°C during the night; at higher elevations it may freeze during the nights in June and July. Humidity is relatively low apart from at the onset of the rainy season. The extreme south-west of South Africa experiences a Mediterranean climate with winter rains and summer dryness.

Topography is generally smooth to undulating, except for some isolated mountain ranges such as the Drakenberg Mountains in South Africa, hill ranges comprising volcanic dykes (e.g. in Zimbabwe) and deep valleys such as the Zambezi Gorge on the border between Zambia and Zimbabwe. Quite typical is the occurrence of many *kopjes* (exfoliated large granite boulders) scattered over the landscape.

Above: Soils with an accumulation of silica are a feature of southern Africa. The photographs shows pieces of Durisol (locally called *dorbank*) that have been mechanically broken up by a ripper plough in semi-arid Western Cape Province, Vredendal, South Africa. This area is used for the production of quality wines under irrigation and no planting is possible on such shallow soil without this soil preparation action. The Durisol occurs on the higher, older terraces along the Olifants River where it is cooler and therefore more suitable for the production of quality white vines such as Sauvignon Blanc. (FE)

Right: A typical "Sandveldt" soil or Albic Acrisol from southern Zambia. The reddish subsoil marks the zone of pronounced clay increase; the textural class shifts from loamy sand/sandy loam in the topsoil to sandy clay/clay in the subsoil. (OS)

Chromic Luvisol in eastern Botswana. Although sufficiently deep and dark, the surface layer is too hard and lacks the required structure to be referred to as mollic. (ISRIC)

Granite "kopje" balancing precariously in Zimbabwe. (ISRIC)

Close up of a Petroplinthite surface in Swaziland. It is clear from this photograph why it is also called ironstone in many parts of Africa. (CG)

Native vegetation is mainly Mopane woodland, with grassland in the shallow valleys (known locally as *dambos* or *vleis*). Much of it has disappeared at the expense of large agricultural enterprises, cities and opencast mines.

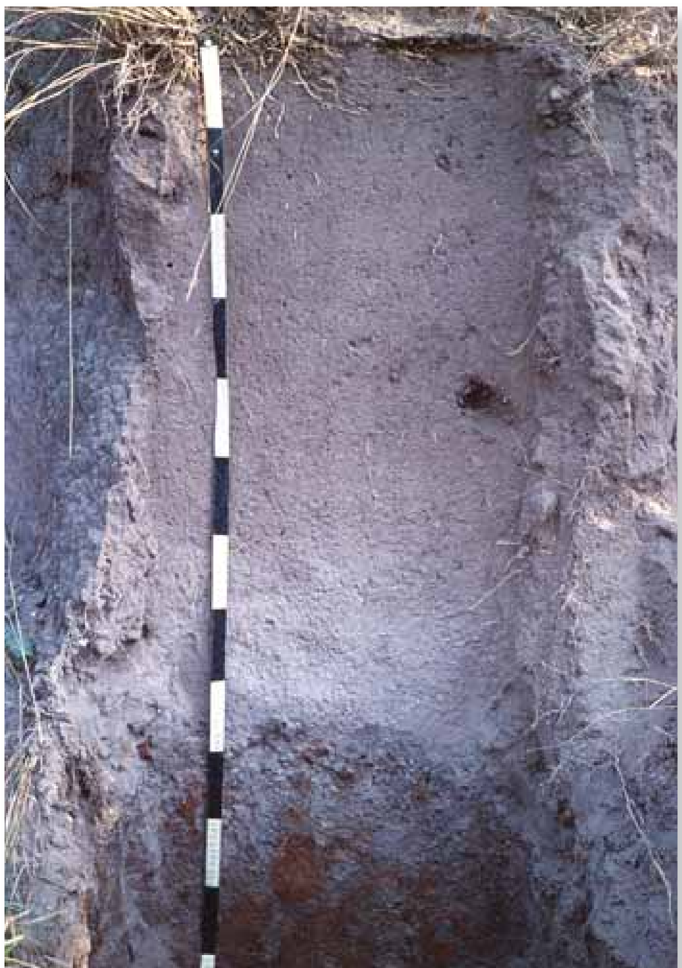
Tourists are drawn to the large game parks in the region, of which the Kruger National Park in South Africa on the border with Mozambique is the most well-known.

The large variety of parent material, the long period of soil formation under relatively stable tectonic conditions, and historical climatic variations (e.g. a long dry period during the Upper Pleistocene) causing considerable changes in vegetation have resulted in a vast array of soils; almost any soil type imaginable can be found. However, the uplands are dominated by sandy soils due to the influence of the Kalahari sands, and soils with a pronounced increase of clay with depth, locally known as *Sandveldt* soils. Depressions or *vleis* are often filled with cracking clays, whereas non- to weakly-developed soils prevail on slopes.

The main soil types of this region are Acrisols, Arenosols, Cambisols, Leptosols, Lixisols, Luvisols, Nitisols, Phaeozems, Regosols and Vertisols. Subdominant soils are Alisols, Calcisols, Gleysols, Ferralsols, Fluvisols, Planosols and Solonetz, while rarer soils include Chernozems, Histosols, Kastanozems, Podzols and Umbrisols.

In areas with a lot of human activity, such as around mines, Technosols can be found.

A comprehensive review the soils of South Africa can be found in [74a].



Arenosol from South Africa. The mottling in the bottom indicates the occasional presence of water in the soil. Provided their roots can reach it, such moisture can sustain plants even if the topsoil appears very dry. (ISRIC)

A Luvic Phaeozem from South Africa with an organc-rich topsoil over weathering bedrock. (ISRIC)

Yacouba Sawadogo (right), the subject of the award winning documentary file 'The Man Who Stopped the Desert' [74], in a field of sorghum in Burkina Faso. The film shows how the quality of soil can be improved through relatively simple and inexpensive techniques. Soil quality is a general term used to describe the ability of the soil to perform its function of sustaining agriculture. There are many parts of the African continent, particularly in South Africa, where the agriculture is characterised by medium or high input systems that are heavily dependent on mechanisation and the inputs of agro-chemicals. Low-input agriculture implies that large-scale irrigation is absent, the use of inorganic fertilisers, pesticides and herbicides is minimal, and soil management does not require high energy mechanised equipment. In Burkina Faso, an ancient farming technique known as Zai was adapted to successfully grow crops on previously abandoned land. (RZ)

Land that is marginal or unsuitable for agriculture, too costly to improve or unable to support more than very low intensity traditional systems should be managed to preserve its ecological quality. These areas may be of benefit to other types of land use such as wetlands needed for breeding fish stocks and wildlife refuges. These marginal lands have been shown to be income producers when managed for wildlife. Kenya, Tanzania (see above), Namibia and Zimbabwe have been successful in attracting tourists to view animals in 'marginal' land set aside as wildlife refuges. (VL)

Key threats to soil

Maintaining soil condition is essential for ensuring the sustainability of society. However, soil is under increasing threat from a wide range of human activities. The threats are complex and although unevenly spread across Africa, their dimension is continental. For simplicity they are presented separately below. However, in reality they are frequently inter-linked. When many threats occur simultaneously, their combined effects tend to increase the problem. Ultimately, if not countered, soil will lose its capacity to carry out its functions. This process is known as soil **degradation**.

According to the only pan-Africa assessment of human-induced soil degradation [75], nearly **500 million hectares, representing more than 16% of the total land area, are affected by some kind of degradation process**. If non-productive land is discounted (i.e. desert, salt pans, lakes and mountains), then some form of soil degradation affects over 22% of the African continent. Overgrazing is the most important cause of human-induced soil degradation in Africa, followed by agricultural mismanagement and deforestation.

Loss of nutrients and/or organic matter occurs if agriculture is practiced on poor or moderately fertile soils, without sufficient application of manure or fertiliser. It causes a general depletion of the soils and leads to decreased production. Nutrients can also be lost after the clearing of natural vegetation. Increasingly, this is one of the most important pressures on soil as it affects food security. If left unchecked, it can lead to a failure of the soil system and trigger the onset of desertification and social upheaval.

Soil degradation, when occurring in dry areas, is known as **desertification** which is caused by climatic conditions (droughts, aridity, irregular and intense precipitation regimes) and human activity (deforestation, overgrazing, soil structure deterioration). The affected land can no longer support vegetation. Desertification has extremely serious socio-economic consequences and can ultimately cause the destabilisation of societies and the migration of human populations. Approximately 26% of Africa is vulnerable to these processes.

Climate change presents an overarching but as yet uncertain factor that can amplify degradation processes.

Soil sealing occurs mainly through the development of technical, social and economic infrastructures, especially in urban areas.

Erosion occurs mainly due to the inappropriate use of soil by agriculture and forestry, but also through uncontrolled building development and uncontrolled water runoff from roads and other sealed surfaces. Approximately 14 million km^2 are affected by wind and water erosion. An estimated 65% of Africa's agricultural land is affected by a loss of topsoil and soil nutrients. Burkina Faso, Burundi, Ethiopia, Madagascar, Lesotho, Morocco and Rwanda are particularly affected.

Decline in biodiversity is linked to the loss of organic matter, because biodiversity depends on organic matter, which means that all soil biota live on the basis of organic matter. There is almost no information on this aspect for Africa.

Contamination is due to a range of human activities, such as industrial production, traffic, the use of fossil material, such as ores, oil, coal and salts, or agricultural activities. It can be diffuse (widespread) or localised. Local contamination constitutes a major problem which has not yet been fully evaluated. Acidification related to gold mining and refining is a serious concern in South Africa.

Compaction and further physical deterioration of soils is a rather new phenomenon caused mainly by high pressures on soil through heavily loaded vehicles in agricultural and forest land use. Also a problem where animal stocking densities are high.

Hydro-geological risks are complex phenomena, resulting in floods and landslides deriving partly from uncontrolled soil and land uses (e.g. sealing, compaction and other adverse impacts) as well as uncontrolled mining activities.

Salinisation is a problem in agricultural areas where saline groundwater or inappropriate irrigation practices lead to an accumulation of salts in the soil which affects plant growth.

Key messages

It is important to analyse these threats in two ways:

- to understand the driving forces behind them and the resulting pressures which lead to adverse effects on soil;
- to understand how the impacts of these threats negatively influence the functions of soils for humankind and the environment.

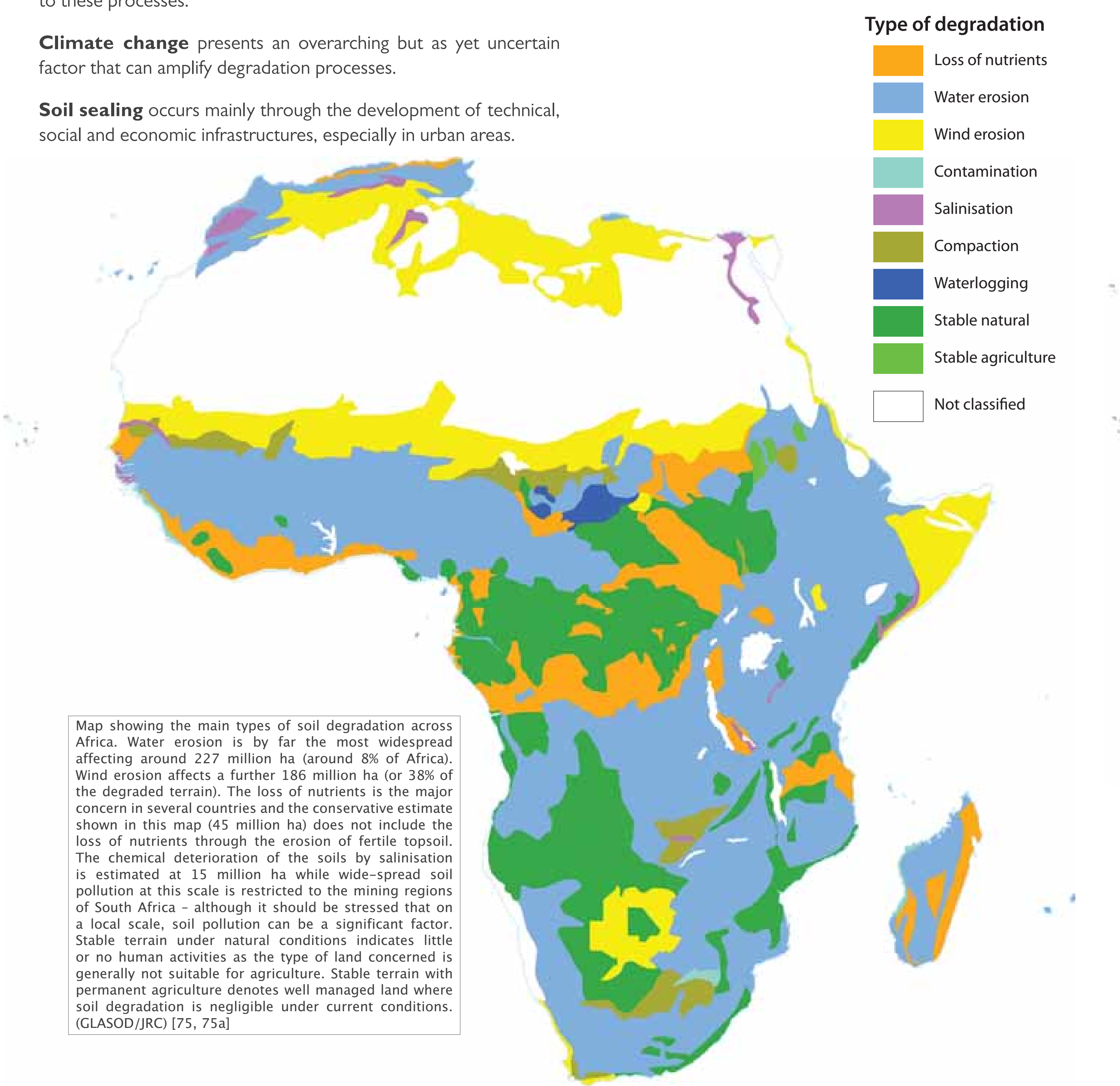
Relating the main threats to driving forces and pressures through cross-linkages with pan-African and national strategies reveals that many agricultural, regional planning, environmental protection, transport, energy development, single market and other policies may have an important influence, because they are partly triggering or inducing threats.

Analysing the impacts of threats by relating them to important soil functions reveals that erosion can be correlated with air pollution, water pollution, decline in biomass production, endangering human health and decline in biodiversity.

It should be stressed that the processes described on this page do not occur in isolation. In most cases, there are strong inter-dependencies between them. For example, the loss of nutrients and low levels of organic matter may cause erosion, facilitate compaction, induce decline in biodiversity and, indirectly, decrease water infiltration therefore increasing the danger of floods and landslides.

Regarding the state of the different threats in Africa, in many cases there is simply not enough information available about their spatial distribution and changes over time. One of the most challenging tasks facing African soil scientists and policy makers will be to create a soil monitoring system to provide detailed information about the development of these key threats across Africa.

While the map to the left shows the type of soil degradation across Africa, in reality the extent and severity of the problem vary from region to region. A small degree of soil degradation on agricultural land may be seen as acceptable by some land owners as the associated reduction in yields and other soil functions do not have an immediate impact on economic and social conditions. However, if left unchecked, the situation may worsen to a point where improvements may be beyond the means of local farmers in developing countries. Data suggests that there are over 124 million ha of strongly degraded soils in Africa and a further 5 million ha are classified as extremely degraded and are considered to be irreclaimable and beyond restoration.



Map showing the main types of soil degradation across Africa. Water erosion is by far the most widespread affecting around 227 million ha (around 8% of Africa). Wind erosion affects a further 186 million ha (or 38% of the degraded terrain). The loss of nutrients is the major concern in several countries and the conservative estimate shown in this map (45 million ha) does not include the loss of nutrients through the erosion of fertile topsoil. The chemical deterioration of the soils by salinisation is estimated at 15 million ha while wide-spread soil pollution at this scale is restricted to the mining regions of South Africa – although it should be stressed that on a local scale, soil pollution can be a significant factor. Stable terrain under natural conditions indicates little or no human activities as the type of land concerned is generally not suitable for agriculture. Stable terrain with permanent agriculture denotes well managed land where soil degradation is negligible under current conditions. (GLASOD/JRC) [75, 75a]

The map shows the areas with the most severe soil degradation, as calculated through a combination of the degree and the relative extent of the process. The map shows where the severity of soil degradation is high and very high. (GLASOD/JRC) [75]

GLASOD

The UNEP-funded GLASOD project produced a global map of human-induced soil degradation. Uniform guidelines and international correlation standards were used to compile a global dataset. The status of soil degradation was mapped on the basis of expert judgement within loosely defined physiographic units (polygons). The type, extent, degree, rate and main causes of degradation were assigned to produce a global map, at a scale of 1:10 million. [75a]

Climate Change

What is climate change?

In the most simple terms, climate can be defined as the typical weather pattern for a specific location over a long period of time. The Earth is divided into several zones that share similar climatic attributes such as temperature, humidity, atmospheric pressure, wind, and precipitation, all of which are affected by latitude, altitude and proximity to the ocean. The World Meteorological Organization uses the weather records over a thirty-year period to define the climate for a particular location. For example, in the Köppen climate classification system, the tropical rainforest climate is characterised by high rainfall (minimum normal annual rainfall between 1 750 and 2 000 mm), all twelve months must have an average precipitation of at least 60 mm and mean monthly temperatures must exceed 18°C [11].

It is clear from the geological and historical records that the climate of a location can change. Over extremely long time scales (tens or hundreds of millions of years,) plate tectonics can reposition continents, create oceans and build or erode entire mountain chains. All these factors can greatly influence the climate. In fact, the collision of the North and South American tectonic plates approximately 3 million years ago, which shut off direct mixing of the Atlantic and Pacific Oceans, has been suggested as one of the main causes of the Pleistocene Ice Ages!

The energy of the sun is a key external factor in determining the Earth's climate. Astronomers believe that, over hundreds of millions of years, the sun is slowly getting brighter, which would mean that the Earth's atmosphere will eventually heat up. On a shorter time scale, the sun exhibits an 11-year sunspot cycle that affects solar radiation levels and weather patterns. While the 11-year cycle does not manifest itself clearly in the climatological data, variations in solar intensity are considered to have been influential in triggering the Little Ice Age (a series of very cold winters from the 16th to the mid-19th centuries – recorded in the lake sediments across Africa) and for some of the global warming trends observed from 1900 to 1950.

In a related manner, slight variations in the Earth's orbit can lead to changes in the distribution and intensity of sunlight reaching the Earth. Such orbital variations, known as Milankovitch cycles, are considered to be the main driving factors behind the swing from glacial to interglacial periods.

Recently, the term 'climate change' has been mainly used to refer to changes in modern climate as a result of human activity. The term is often applied synonymously to describe the rise in average surface temperature known as global warming. Scientists believe that this warming is caused by increased concentrations of carbon dioxide (CO_2), one of the major greenhouse gases. Since the industrial revolution of the 1850s, the consumption of fossil fuels (i.e. coal, oil, natural gas) has raised CO_2 levels in the atmosphere significantly. Along with rising methane levels, these changes are predicted to increase average global temperature by 5°C during the period 1990 to 2100 [76].

Greenhouse Gases

The Earth's atmosphere contains approximately 78% nitrogen, 21% oxygen, a variable amount of water vapour (generally around 1%), argon (just under 1%), 0.04% carbon dioxide and traces of hydrogen, helium and other gases.

Certain gases in the atmosphere absorb solar radiation and trap heat. This phenomenon is called the 'greenhouse effect' and the gases which contribute to this effect are referred to as greenhouse gases (GHGs). The major GHGs are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4) and ozone (O_3). Other GHGs include nitrous oxide (N_2O), sulphur dioxide (SO_2) and hydro-fluorocarbons (HFCs).

Climate change: Adaptation or Mitigation?

Mitigation describes efforts to reduce the sources and enhance the sinks of greenhouse gases. Examples include the more efficient use of fossil fuels, switching to renewable energy and expanding forests or increasing soil carbon stocks to remove greater amounts of carbon dioxide from the atmosphere.

In contrast, *adaptation* involves altering practices to tolerate the effects of climate change. Examples range from the use of drought-tolerant crops, increased rainwater storage and updated irrigation technology to wholesale changes to the agricultural production system.

What's happening to the climate of Africa?

The climate of Africa ranges from equatorial rainforest to subarctic on its highest peaks. As much of Africa lies in the tropics, large expanses of rainforest and deserts experience stable climates with little seasonal variability. In these, situations, the evidence for climate change may be difficult to identify. However, in more marginal areas, there is clear evidence of major variations in climate during the past fifty years. The droughts and associated famines of the Sahel and Ethiopia have been extensively documented and clearly demonstrate the human consequence of climate change.

In fact, the historical climate record for Africa shows warming of approximately 0.7°C over most of the continent during the 20th century, with some areas warming faster than others (Rwanda increased by 0.7°C to 0.9°C over 50 years). This change was accompanied by a decrease in rainfall over large portions of the Sahel, and an increase in rainfall in east central Africa. The marked decline in rainfall has resulted in a significant reduction in surface area of most natural wetlands, as exemplified by Lake Chad, whose surface area has shrunk from 20 000 km² in the 1970s to 7 000 km² today. [47]

Prognosis?

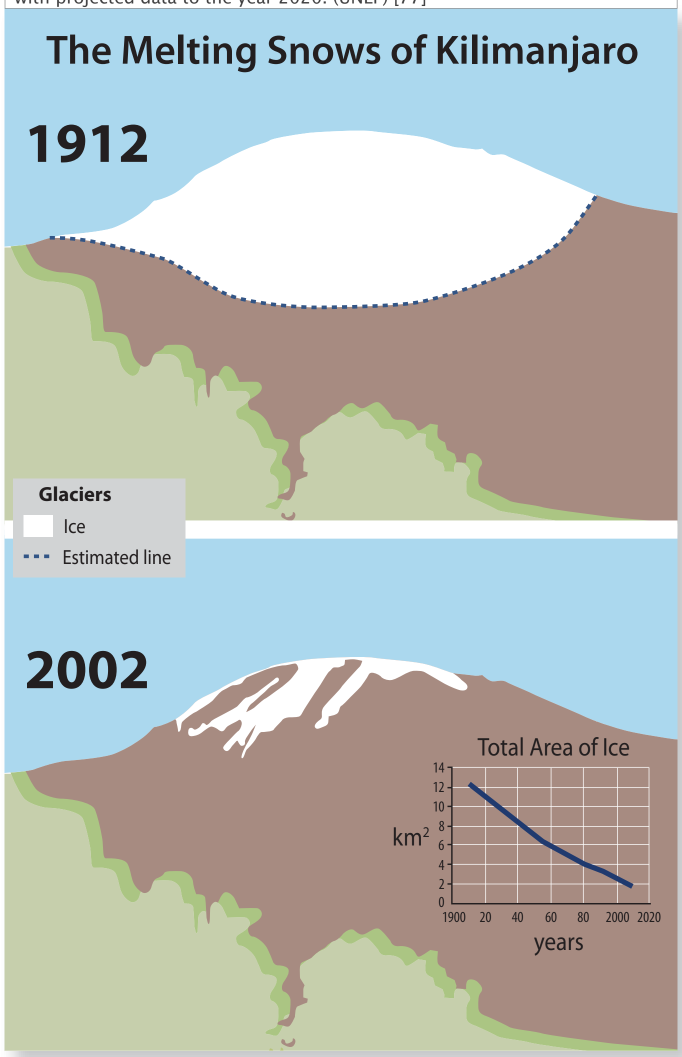
Climate change scenarios for Africa, based on results from several general circulation models using data collated by the Intergovernmental Panel on Climate Change (IPCC), indicate a warming across Africa ranging from 0.2°C per decade (low scenario) to more than 0.5°C per decade (high scenario). This warming is greatest over the interior of semi-arid margins of the Sahara and central southern Africa. [47]

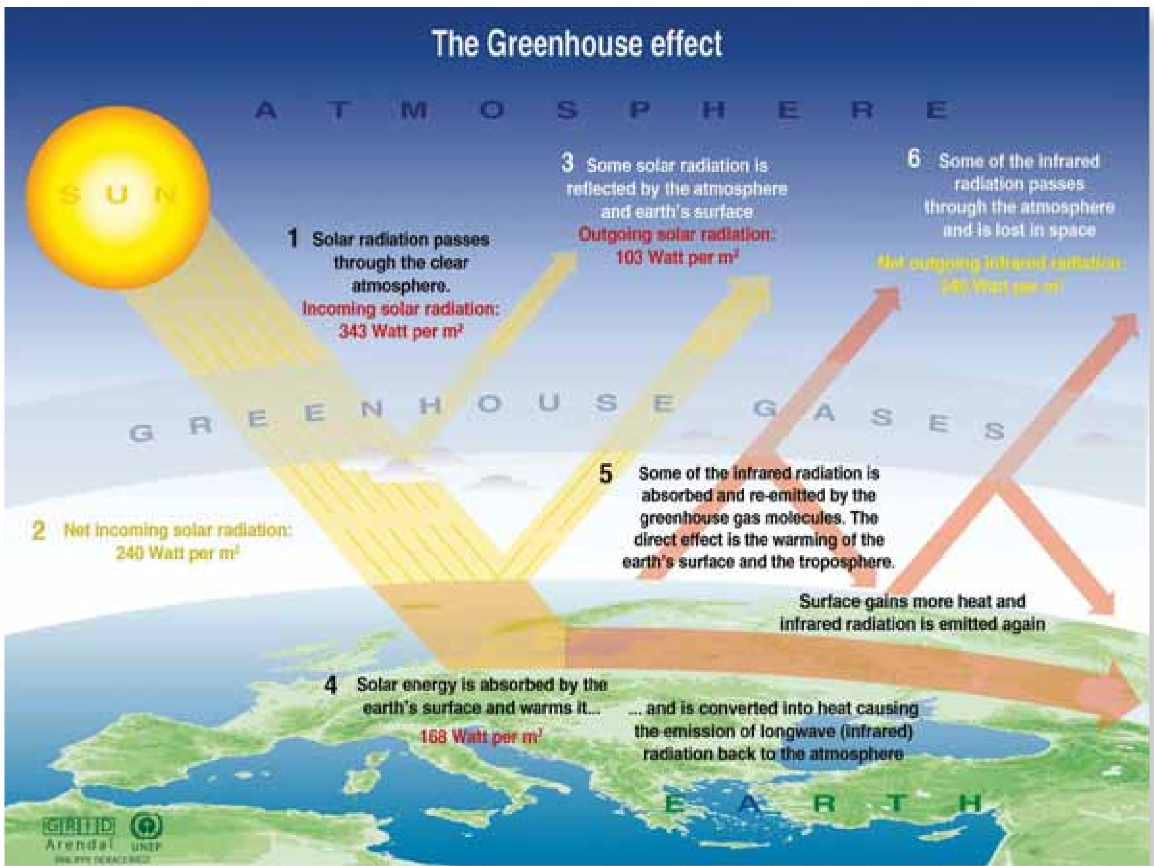
Projected future changes in mean seasonal rainfall in Africa are less well defined. Under the low-warming scenario, few areas show trends that significantly exceed natural 30-year variability. Under intermediate warming scenarios, most models project that by 2050 northern Africa and the interior of southern Africa will experience noticeable decreases in precipitation during the growing season; in parts of equatorial east Africa, rainfall is predicted to increase in December–February and decrease in June–August. [47]

It should be stressed that this assessment of climate change is marked by uncertainty. The diversity of African climates, high rainfall variability and a very limited observational network make predictions of future climate change difficult at the sub-regional and local levels.

Above: A zone that is sensitive to climate change is the high, snow-capped equatorial peaks of Africa. Despite lying close to the Equator, the summits of the Ruwenzori range, Mount Kenya and Kilimanjaro (all over 5 000 m in elevation) are capped by snow, glaciers and ice-fields throughout the year. Given their precarious position, any variation in temperature or precipitation should affect the extent of the snow and ice. (AJ)

Below: The illustration clearly shows the retreat of the ice on Kilimanjaro. The graphic shows the estimated extents of the glacier on Mount Kilimanjaro in 1912 and 2002. Some studies show that Kilimanjaro has lost 82% of its ice cover over the last one hundred years, while Mount Kenya has lost 92%. The graphic also shows the decline in the total area of the ice from 1900 to 2000, with projected data to the year 2020. (UNEP) [77]





Human activities are causing greenhouse gas levels in the atmosphere to increase. This graphic explains how solar energy is absorbed by the earth's surface, causing the earth to warm and to emit infrared radiation. The greenhouse gases then trap the infrared radiation, thus warming the atmosphere. (UNEP) [77a]

Consequences

It is likely that Africa will face some degree of climate change impacts over the next 50 to 80 years. However, given that so much of Africa is already experiencing pressures from a range of issues (poverty, food insecurity, land degradation, conflict) and its heavy reliance on rain-fed agriculture, it is clear that climate change will only exacerbate the situation with notable consequences for agriculture, forestry, the environment, civil engineering and the preservation of cultural heritage. Issues that are of particular significance are:

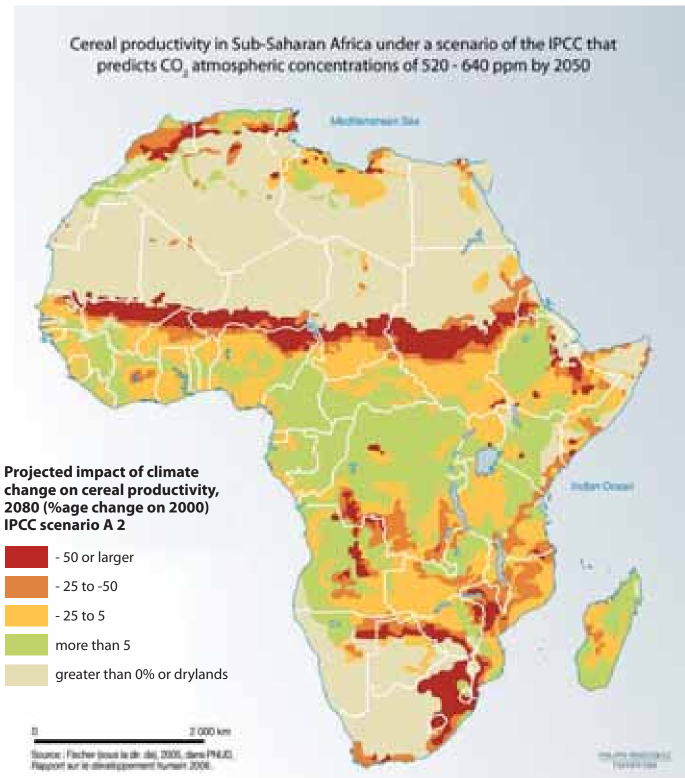
- the supply and availability of water resources,
- food security risk from declining agricultural production;
- loss of biodiversity and natural resources from habitat loss;
- increasing outbreaks of diseases aggravated by malnutrition;
- sea-level rise leading to flooding in coastal zones,
- loss of fertile topsoil and damage to infrastructure from extreme weather events;
- exacerbation of desertification from reduction in rainfall and intensified land use.

In the context of this atlas, land-use changes will continue to be a major driver of soil condition across Africa. Resultant changes in ecosystem type and extent will affect the distribution and productivity of plant species, water supply, nutrient cycling and other services. Losses of soil functions are likely to be accelerated by climate change with potential feedback effects on the human population of Africa, its environment and, eventually, on the global climate system.

Much of the population of Sub-Saharan African lives in rural areas where income and employment depend almost entirely on rain-fed agriculture. This population is at high risk. Sub-Saharan Africa already has a highly variable and unpredictable climate that is acutely vulnerable to floods and droughts. A third of the people in the region live in drought-prone areas, and floods are a recurrent threat in several countries. With climate change, large parts of the region will become drier, increasing the number of people at risk of hunger and poverty by tens of millions.

Climate-induced changes to crop yields and ecosystem boundaries will dramatically affect some of the poorest people in sub-Saharan Africa partly because many of them live in areas most prone to extreme climate events and partly because they have little capacity to adapt by turning to irrigated agriculture, improved seeds or alternative livelihoods. Recent modelling has provided important insights that should serve as an early warning system.

It is ironic that although Africa contributes the least to the greenhouse gas (GHG) emissions through fossil fuel emissions, it is likely to suffer the most.



Cereal productivity in sub-Saharan Africa under a projected Intergovernmental Panel on Climate Change (IPCC) scenario. The map, is based on the relationship between water availability and productivity in the cereals sector. It highlights areas of acute threat that includes a wide band across the Sahel region, stretching from Mauritania across Niger, Burkina Faso, Chad and Sudan. Large swathes of southern Africa face the prospect of steep declines in yields, along with chronically food-insecure countries such as Ethiopia and Somalia. (UNDP) [78, 78a, 78b]

Climate change and soil: the hidden cycle

As climate is a major soil forming factor, it is clear that climate change is likely to affect soils in a variety of ways, predominantly by altering the key processes that underpin the capability of soils to perform their key functions. Temperature, rainfall and changes in atmospheric carbon dioxide also affect soil ecology and organic matter levels which in turn determine soil characteristics such as structure, water regimes, pH and nutrient levels. Over time, changes to these properties will lead to significantly different soil types. However, it is very difficult to accurately predict the effects of climate change on varied and complex, three-dimensional soil systems. However, higher temperatures also promote a more rapid breakdown of organic matter in the soil due to a thermal boost to microbial activity. This accelerates the release of carbon dioxide and methane into the atmosphere through increased soil respiration.

Changes in precipitation and more extreme hydrological cycles (as predicted across much of Africa) means that soils will either experience intense rain storms or prolonged periods with lower levels of precipitation. Either situation, or even a combination of both, could lead to increased vulnerability to erosion which can result in the loss of topsoil nutrients and stored carbon either as greenhouse gas emissions to the atmosphere or as particulate organic carbon. Additionally, the rate of organic matter decomposition also depends on soil moisture levels. Changes in rainfall patterns can also affect soil structure and acidity levels. Together with organic matter content, these characteristics define the ability of a soil to store water and sustain many of the organisms that live within it.

One positive view of climate change is that a combination of slightly warmer and wetter conditions will generally stimulate higher levels of plant growth with increased production of biomass and organic matter in the soil. Such conditions also heighten chemical weathering, which in turn releases essential minerals and nutrients from parent material and contributes to the development of the soil body. Under such conditions, crop growth may be possible in areas where currently the constraints to agriculture are too severe.

Rice on beds and furrows of Vertisols of the Fogera Plains of Lake Tana, Ethiopia. Agricultural production and food security in many African countries and regions are likely to be severely compromised by climate change and climate variability. Understanding the responses of soil to changes in climate is a critical process in developing both mitigation and adaptation strategies. However, soils are a complex medium and the reaction of soils will vary according to their inherent characteristics. (JD)

Soil and climate: a way forward?

A more sustainable approach to land management could see soils playing a significant role in reducing the impact of climate change by taking carbon out of the atmosphere and storing it in soil.

A priority should be given to protect soils with the highest carbon content – namely peat soils and carbon-rich permanent pastures and forests.

Improvements in soil-management practices can have considerable impact on carbon stocks. Changes to agriculture techniques (see discussion on conservation agriculture on page 153) can minimise carbon losses. Of particular relevance are the management of crop residues, which ensure that soils are protected against erosion through increased vegetation cover, together with less-intrusive soil tillage techniques. The widespread adoption of such practices could avoid the release of carbon from soils, but would help sequester millions of tonnes of carbon per year.

On cropland, soil carbon stocks can be increased by:

- return of biomass to the soil;
- tillage and residue management;
- water management;
- agro-forestry.

On grassland, soil carbon stocks are affected by:

- grazing intensity;
- grassland productivity;
- species management.

On forest lands, soil carbon stocks can be increased by:

- species selection;
- stand management (e.g. avoiding clear cuts, low-impact logging);
- appropriate site preparation;
- undergrowth control;
- fire management;
- protection against disturbances;
- prevention of harvest residue removal.

On cultivated peat soils, the loss of soil carbon can be reduced by:

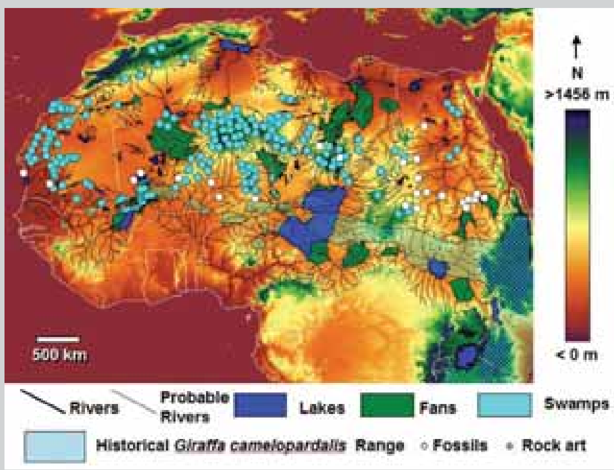
- higher groundwater tables.

On unmanaged peatlands, soil carbon stocks are affected by:

- water table (drainage);
- burning;
- grazing.

Evidence of past climate change in the Sahara

Following the end of the last glacial period (between 10 - 15 000 years ago), the monsoon rains in Africa grew stronger and spread northward into the Sahara. Instead of being the sandy desert we see today, the Sahara was covered in rivers and lakes and supported a savannah-like landscape. Humans occupied the region hunting animals such as buffaloes and gazelles while crocodiles and giraffes were common. This is evidenced by the occurrence in the central Sahara of the fossils and cave paintings of mammals, amphibians, reptiles (and even fish), creatures that normally occupy more humid environments. The ancient river networks, together with the dried lakes and swamp deposits, now act as parent materials for soil (see map below).



However, about 5 500 years ago, the situation began to change. Rainfall levels decreased causing more arid conditions to develop which in turn led to a reduction in the vegetation levels. This change has been confirmed from the record of dust that is transported from Africa into the Atlantic Ocean, which is inversely related to the amount of vegetation. Prior to 5 500 years ago, vegetation was more extensive in northern Africa as there was little loss of sediment from the land while afterwards, the reverse is true.

While the exact causes are not totally understood, many scientists believe that the main driver was a slow but regular change in the Earth's orbital parameters which, in turn, affected the amount of solar radiation energy received by the Earth.

Map showing the late Pleistocene and Early Holocene palaeo-hydrology of the Sahara (i.e. ~11-8000 years ago). The historical and Holocene distribution of the common giraffe (*Giraffa camelopardalis*) is indicated. The pattern is derived through the location of rock art and fossils. The map clearly shows a trans-Sahara distribution, both across the then green Sahara and down the Nile Valley, indicating a climate and landscape that were once significantly more humid than which exists today. The location of giant paleo-lakes such as Megachad, the Niger Delta and the Chott basin of Algeria and Tunisia are clearly shown, as are the associated river networks and contemporaneous alluvial fan deposits. Many of these features produced distinctive parent materials, leading to the formation of soils such as Vertisols, Solonchaks and Fluvisols.

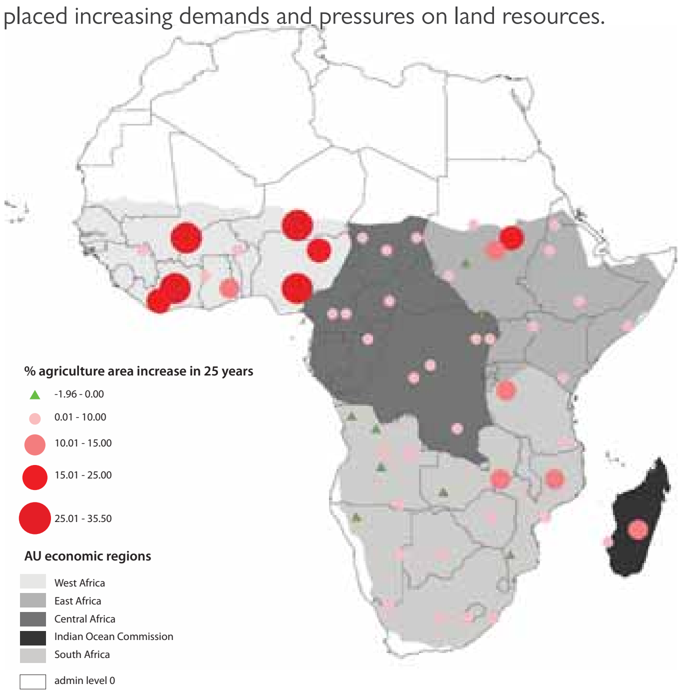
Deposits suggests that at its peak, Lake Megachad was over 170 m deep and covered an area of roughly 400,000 km^2. The present Lake Chad has a maximum depth of 11 m and an area of only 1,350 km^2. (ND) [79]

Land management and soil

Without doubt, human activity and how the land is managed is having a major impact on soil characteristics and the provision of soil functions across large parts of Africa. This is not a new phenomenon. Through practices such as slash and burn, ploughing and liming, human beings have been modifying soil properties over millennia. Indeed, where the climate supports long-term arable farming practices, the current soil characteristics may be very different to when the land was under natural vegetation. Unfortunately, in recent years, increasing pressure on the land to support an exploding population and economic development means that much of this impact is giving rise to soil degradation. This section describes three issues that affect soil quality and impact on food security.

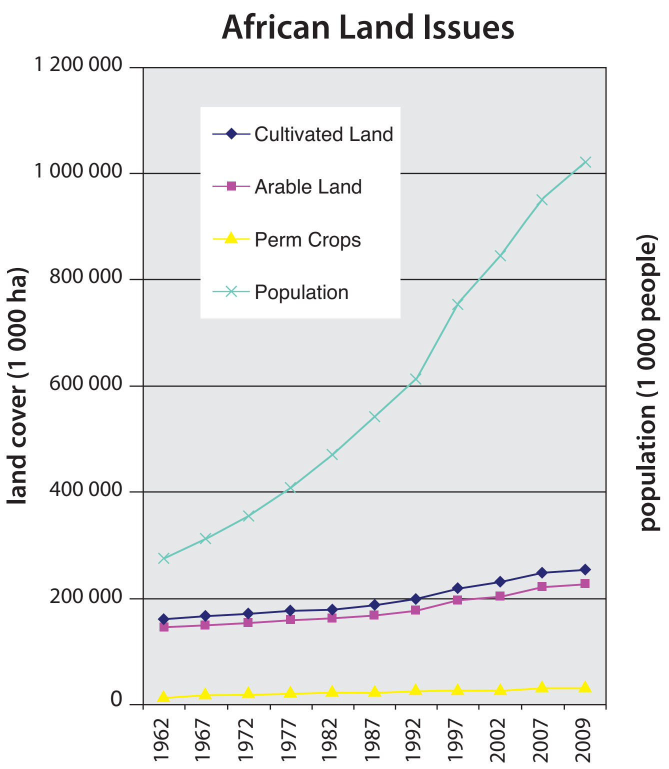
1. Land use change and soil quality

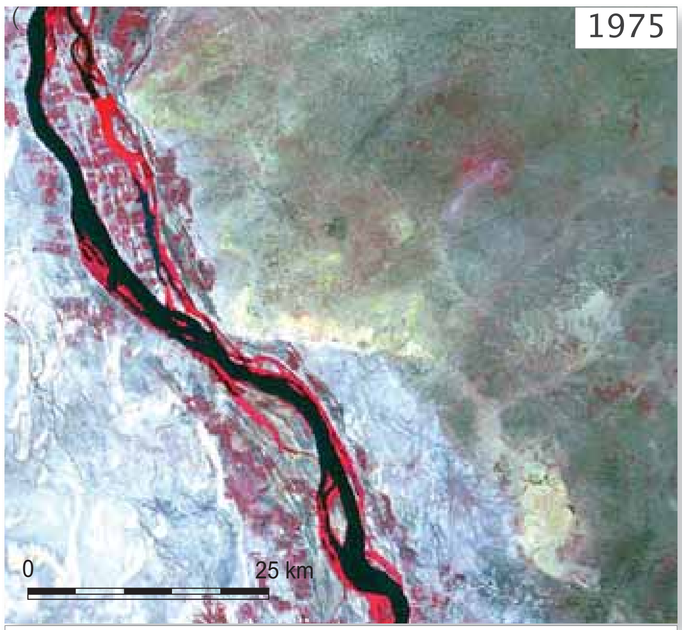
Since the late 1960s, there have been unprecedented land cover and land use changes throughout Africa. This has been especially evident in the Sub-Saharan region where a high rate of population increase, economic development and natural hazards such as droughts have placed increasing demands and pressures on land resources.



Above: Analysis by the JRC of satellite data for the period 1975 to 2000 has shown that Sub-Saharan Africa has lost 16% of its forests and 5% of its woodlands and grasslands, equating to a loss of over 50 000 km² per year of natural vegetation (equivalent to clearing almost three times the land area of Swaziland (17 363 km²) every year!). The majority of this has been converted to agricultural use, predominantly under arable crops. (AB) [80]

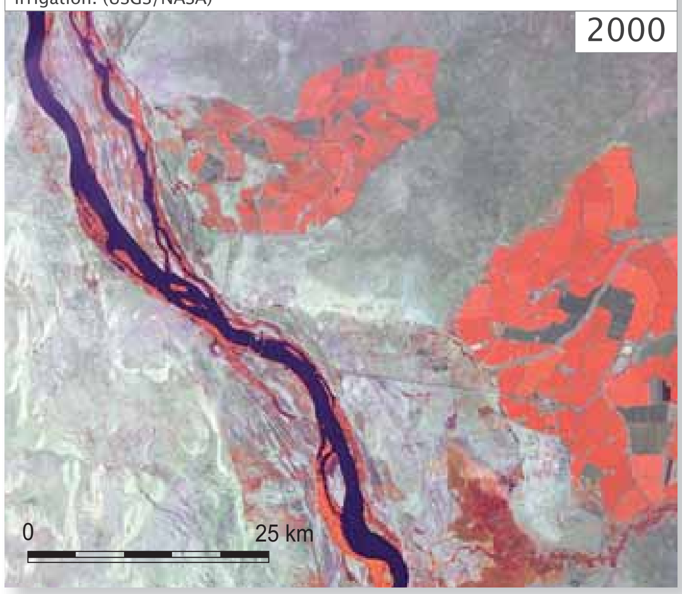
Below: Most cultivated land in Africa is given to arable production (i.e. under temporary crops, temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow for less than five years). Statistics collected by the FAO show a 59% increase in cultivated land (arable land + land under permanent crops) across the whole of Africa between 1962 and 2009 while the population of Africa rose by 271% during the same period. While the area of permanent crops has doubled since 1962, the area given over to arable has increased significantly. The left Y-axis represents 1 000 ha for the land cover lines while the right Y-axis represents 1 000 people for the population line. (FAO Aquastat/JRC) [81]

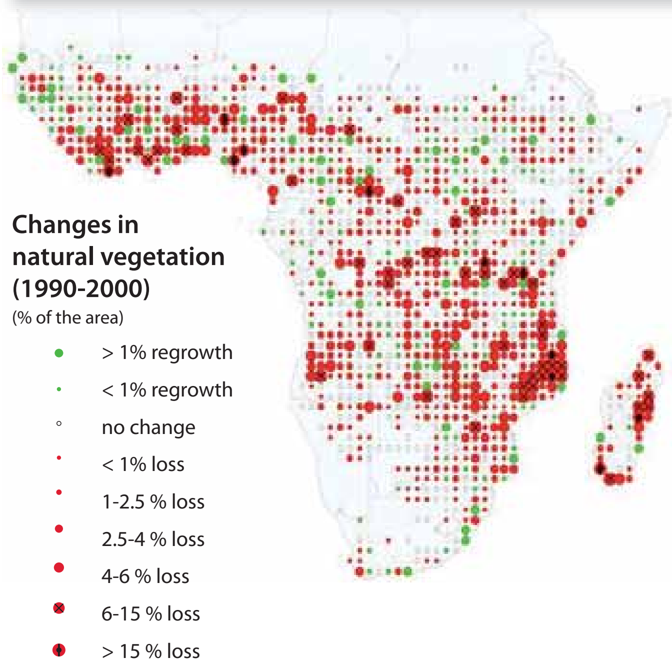




Above: An image from the Landsat satellite of a section of the River Nile in Sudan captured in 1975 (near the town of Kosti). Green vegetation appears as red colours while unvegetated surfaces are light blue and shrubby grasslands are olive-green. (USGS/NASA)

Below: The corresponding area acquired by Landsat in 2000. Note the tremendous increase in cultivated areas (red and pink colours) to the right of the Nile in twenty-five years. The principle driver is the introduction of irrigation. (USGS/NASA)





Above: Changes in extent of woody vegetation in Sub-Saharan Africa between 1990 and 2000. Deforestation is most pronounced in Northern Mozambique, Madagascar and the Côte d'Ivoire. (AB) [82]

Below: A dramatic example of deforestation in the DR Congo. (PM)

- **Impact on soil**

The reduction of natural vegetation systems has a complex impact on soil characteristics. The removal of tropical woodland breaks the fragile nutrient cycle that sustains the above-ground habitat. As a consequence of their inherently low nutrient status, many cleared forest soils often show a marked loss in productivity after a few years of cultivation (unless lime and mineral fertilisers are added). The removal of the protective forest canopy also increases the risk of soil erosion by water, especially in areas where rainfall is high and heavy downpours are common. Carbon locked in the soil is more likely to be oxidised by the clearance processed or washed away by erosion. Compaction can be an issue on some soils and in soils with coarse textures (e.g. Ferralsols), water retention may be low.

Conversely, in drier grassland regions, the change to soil conditions may initially appear beneficial. The cultivation of irrigated cereal crops with low-tillage techniques may, in the short term, actually increase soil moisture, organic matter and biodiversity levels and give higher yields than the natural savannah. However, the reduction in natural grazing areas in marginal or semi-marginal areas may increase the level of burden on other lands. Over-stocking and over-grazing can lead to compaction, a loss of soil cohesion and structure that increases the risk of erosion. The build up of salts in the soils of irrigated areas can eventually lead to a reduction in yield if not managed correctly (see page 157).

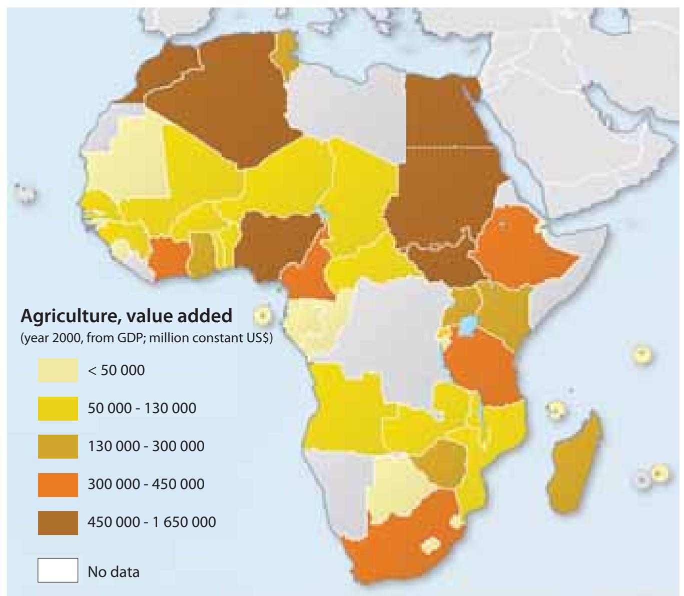
2. Population growth

The graph on the lower-left corner of this page shows the constant and rapid rise of the population of Africa over the past fifty years. According to statistics collected by the United Nations, the population of Africa has increased by nearly 300% since the early 1960s and actually doubled between 1982 and 2009. While there is always some uncertainty over the exact figure, there is general agreement that the population of Africa is now around 1 billion and growing at around 3% per year.

The same figure also shows the corresponding trends in the extent of cultivated land. In 1962, each hectare of cultivated land in Africa had to support 1.91 persons. By 2009, this had risen to 4.55 persons. If we consider that a significant portion of the arable harvest is designated for export, then the ratio of people to land under local food production would be even higher!

- **Impact on soil**

This trend puts tremendous pressure on the soils of Africa. Higher and higher demands are placed on existing agricultural soils with expansion into more marginal conditions. The low-level of fertiliser application in Africa means that nutrient levels are falling dramatically (see adjacent page) leading to stressed cultivation conditions. In such cases, the advent of drought can cause primary soil functions to fail and the agricultural system will collapse raising the risk of malnutrition, mass migration, social tension and potential conflict.



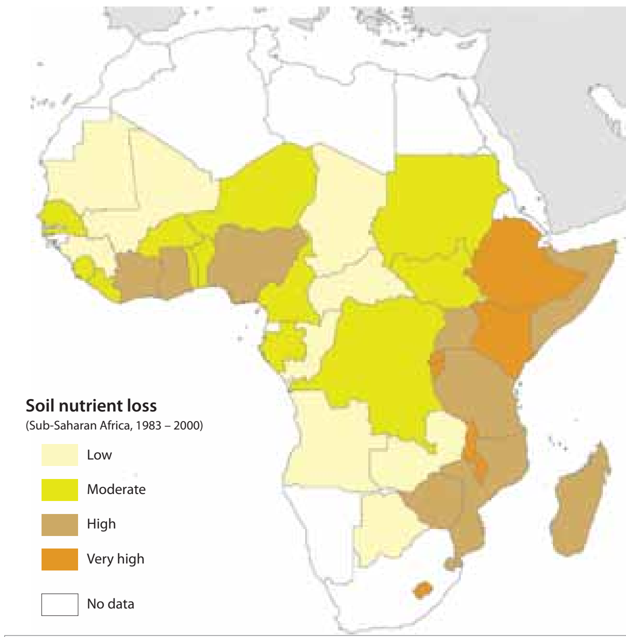
Agriculture is vital to Africa's economic growth, food security, and poverty alleviation. It is the main source of employment for at least 65% of Africa's population and accounts for a significant portion of the gross domestic product (GDP) of most African countries. In this respect, the sustainable management of soils should be of paramount importance and a priority of national governments. (UNEP) [83]

3. Nutrient depletion

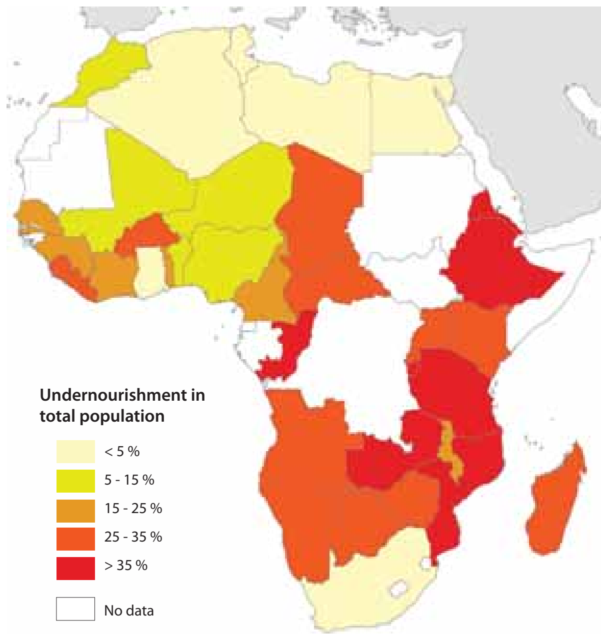
The population explosion that has occurred over recent decades means that there is now even more pressure on the soils of Africa. Yet to support its growing, increasingly urban population, agricultural production in much of Africa is hampered by the predominance of inherently low soil fertility, fragile ecosystems that do not support intensive agriculture and the very low use of mineral fertilisers. Indeed, Africa is yet to display the dramatic increases in agricultural production that have been observed in Asia. The fact that fertiliser use in Africa is less than 10% of that in Asia explains much of the contrasting trends in these regions. At the same time, intensive cultivation often focuses on the production of cash crops for export as a means of raising revenue, often at the expense of local food production.

Farmers in Sub-Saharan Africa traditionally practiced shifting cultivation. Land would be cleared to grow a few crops for 3-4 years before moving on to a new area where the cycle would start again. In this way, the land left behind was allowed to regain fertility. However, intense population pressures and political restrictions on movement now force farmers to grow crop after crop in the same soil. With little access to fertilisers, the movement of harvested crops to towns and villages is essentially exporting soil nutrients and the soils are being depleted or "mined" of their nutrients.

This decline in the fertility of African soils is causing decreased crop yields, a reduction in per capita food production, land degradation and environmental damage. In recent years, food insecurity has been an increasing issue in many parts of Africa. With the population growing around 3% annually, the FAO has reported that the number of malnourished people in Africa has grown from about 88 million in 1970 to more than 240 million by 2010. The maps on this page show that the loss of soil productivity is closely linked to levels of hunger and malnutrition.



Map of estimated nutrient loss from soil for Sub-Saharan Africa 1983-2000. Densely populated and hilly countries in the Rift Valley area show the highest losses owing to high levels of arable land, relatively high crop yields and significant erosion levels. For the area as a whole, the nutrient losses have been calculated as -22 kg/ha in 1983 and -26 kg/ha in 2000 for N; -2.5 kg/ha in 1983 and -3.0 in 2000 for P; and -15 kg/ha in 1983 and -19 kg/ha in 2000 for K. While such data are difficult to measure, more recent studies show no change in this trend. (FAO/JRC) [29]



Map showing the proportion of undernourished people in the period 2010-2012. Note the correspondence with the map to the **left**. (FAO/JRC) [84]

- **Impact on soil**

The continued increase in the area of cultivated land shows that farmers in Africa are being forced to turn to more marginal conditions where soil characteristics may place more constraints on agriculture (see page 35). In many areas, this expansion into less fertile soils is often at the expense of Africa's wildlife and forests.

In time, the decreasing fertility will cause the crop cover to be less extensive. Plants provide protective cover on the land and prevent soil erosion by slowing down water as it flows over the land, protecting the soil surface from the impact of rainfall while plant roots hold the soil in position and prevent it from being washed away.

Over-cultivation and compaction cause the soil to lose its structure and cohesion to the point at which it becomes more easily eroded. As erosion will remove the top-soil first, plant growth will be more difficult once this nutrient-rich layer has gone. Without soil and plants the land becomes barren and unable to support plant, animal or human life - this process is called desertification (see page 154 in this section). It is very difficult and often impossible to restore highly degraded land, especially in the context of human time spans. The consequences became greatly exacerbated under the effects of climate change.

Conservation Agriculture

In conventional intensive agriculture, continuous ploughing and harrowing, the removal or burning of crop residues, mono-cropping and the excessive use of agro-chemicals can lead to a loss of soil fertility and decreasing yields, soil erosion, increased vulnerability to drought and floods and a loss of soil biodiversity. In response, low-cost and low-tech conservation tillage systems have been developed to protect the soil and reduce erosion. The goal of conservation agriculture is to maintain and improve crop yields and resilience against drought and other hazards, while at the same time protecting and stimulating essential soil functions. [85, 85a, 85b]

The two essential features of conservation agriculture are no- or low-tillage and the maintenance of a cover on the soil surface from live or dead plant remains. Crops are seeded or planted through this cover. The soil cover inhibits the germination of many weeds thus maximising nutrient and water availability to the crop. Conservation agriculture also involves inter-cropping and crop rotation.

Experience has shown that conservation agriculture systems achieve yield levels as high as comparable conventional agricultural systems but with less fluctuations due to natural disasters such as drought and storms. Therefore, conservation agriculture contributes to local and regional food security, reduces health risks (well nourished people are better able to recover from illness and diseases such as malaria) and reduces the burden on the State (e.g. less road and waterway maintenance, less emergency assistance).

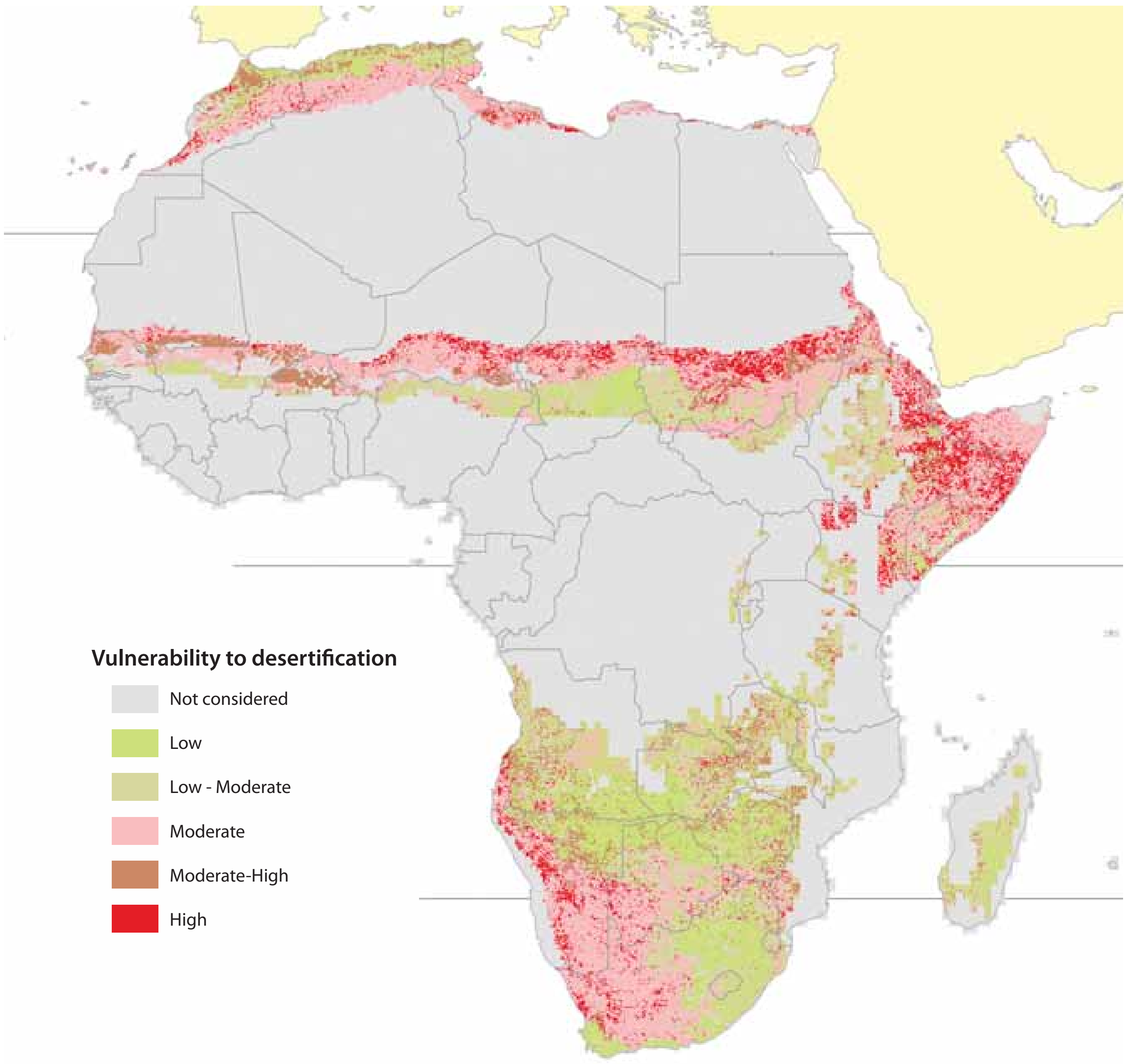
Conservation agriculture (CA) and the improved management of soil also contribute to wider environmental benefits such as less flooding, less erosion (and reduced siltation), more constant flow in the rivers, better recharge of groundwater resources, increased carbon sequestration, less carbon release (less fuel used) and increased biodiversity through diversification.

For more information and documentation on CA in Africa, please visit the FAO Conservation Agriculture Portal:

http://www.fao.org/ag/ca/index.html

Clockwise from left: A major principle of conservation agriculture is that the soil surface should be covered to prevent erosion and discourage weeds. The next crop grows through the discarded leaves, husks and stems of the previous harvest (BO); The soil is disturbed as little as possible - this picture shows a field that has been ripped to receive seeds for the next crop. This approach greatly reduces the soil disturbance - note the complete cover of the soil (BO); Conventional arable agriculture - soil is bare after ploughing (CAVS); Oxen-drawn furrow-seeder. A single piece of machinery opens the soil, plants the seed and applies fertiliser. The use of animals in combination with such technology greatly reduces the risk of soil compaction (BO); The eventual goal is a fertile soil that has high aggregate stability, good structure, high moisture holding capacity, high organic matter levels and is capable of supporting life both below and above ground. (BO)

Desertification and land degradation



Map of estimated areas under risk of desertification. Developing a quantitative indicator of desertification is a complex process due to the availability of data and the considerable ambiguities associated with the term (for which more than one hundred formal definitions have been identified). This map is based on preparatory work being carried out for the forthcoming World Atlas of Desertification (see box below) and provides an estimate of areas under risk of desertification based on the MEDALUS Environmental Sensitive Areas **methodology** which considers climate, soil quality, vegetation and land management issues. Areas that are already desert are excluded as are regions with a tropical climate (A*code in the Koppen system). As expected, the semi-arid desert fringes (with shallow soils that are prone to erosion, low soil organic carbon content and fertility levels) show the highest susceptibility to desertification. However, the novel methodology used to produce this map confirms that significant areas of the continent are experiencing significant levels of vulnerability to degradation. Approximately 26% of Africa is vulnerable to desertification with about 4,500,000 km^2 or 55% of the considered land area at moderate to high risk. Even areas of low vulnerability could be threatened by desertification under significant climate change, if a particular combination of land use were to be implemented. Under the MEDALUS model, nearly flat, well-drained areas with deep to very deep, coarse-textured or finer soils, under semi-arid or wetter climatic conditions, independently of vegetation are considered as not being under threat from desertification. (JRC) [86]

Desertification

Land degradation is a global phenomenon that is reflected by a reduced capacity of the land and soil to sustainably produce ecosystem services and economic value. It is linked to complex patterns of extreme events, climate and land use change. According to the UN Convention to Combat Desertification, the term 'desertification' denotes a reduction or loss of the biological or economic productivity of soils in arid, semi-arid and dry sub-humid areas resulting from a combination of human activities, a deterioration of the land to support core ecosystem functions, coupled with a long-term loss of natural vegetation [87].

Climatic conditions and intensive agriculture make the many parts of Africa particularly vulnerable. Ever more demanding land use leads to water scarcity, hence limiting several ecosystem services normally provided by soil. Amplified variability of aridity limits the ability of intensively used human-environment systems to recover from specific pressures such as drought and fire. In turn, this leads to an increase in land degradation and desertification.

Various estimates show that desertification is affecting about 40% of Africa, a remarkable statistic given that a further 47% of the land area is characterised as desert (only around 13% of Africa is defined as humid). From the map above, around 3 million km^2 are classed as being under a very high risk. The region that has the highest propensity is located along the desert margins.

Most rural inhabitants of dry lands suffer from poor economic and social conditions, made worse by soil degradation and the associated reduction in the productivity of the land. Overpopulation, overgrazing, land exhaustion and over-exploitation of groundwater resources of existing marginally-productive lands creates a cycle which ends in the collapse of agriculture and the social system.

Due to its complex pattern and inter-relational aspect of the key drivers, accurate projections of desertification are difficult to produce and verify. Increased recurrence of extreme events, such as droughts, combined with risks, such as fires, and an expansion of intensive land use will probably induce higher levels of land degradation, including soil erosion, and, in turn, reduce the quality and availability of natural resources and ecosystem services.

Key measures to reduce desertification include adopting sustainable land management practices to cope with higher risks of droughts, for example by changing tillage, crop selection and rotation.

World Atlas of Desertification

The European Commission's Joint Research Centre (JRC), in partnership with the United Nations Environment Programme (UNEP), is compiling a new World Atlas of Desertification that builds on recent scientific progress. It aims to be a pragmatic exercise and an example of how to implement up-to-date concepts and robust approaches for assessing and mapping land degradation and desertification.

The World Atlas of Desertification is expected to be the foundation for better addressing and including desertification and land degradation in strategies that address food security, resource efficiency, energy and emissions schemes, development and poverty reduction.

http://wad.jrc.ec.europa.eu/index.php

Deserts

The term 'desert' is used to describe land that receives an extremely low amount of precipitation and where the soil moisture balance is negative (i.e. more water is lost by evapo-transpiration than received from precipitation). Average annual precipitation of less than 250 mm is insufficient to support the growth of most plants.

Africa is the world's second driest continent with a very uneven distribution of rainfall. The desert lands of the Sahara, Namib and Kalahari, as well as the dry lands of northern Kenya, southern Ethiopia and most of Somalia cover around 40% of the land surface of Africa. According to the UN, renewable water resources for the whole of Africa are less than 9% of the global total. Enormous underground water sources are increasingly being exploited to support agriculture in desert regions (see pages 21 and 155). However, this is relict or fossilised water and is not a sustainable resource in the long term.

Not all deserts are hot! Regions characterised by low precipitation and low temperatures are known as cold deserts. Often, any moisture comes as snow or fog. The coast of the Namib is regarded as a cold desert. The soils of cold and hot deserts are very similar, primarily due to a lack of organic matter and moisture-driven soil processes!

The United Nations Convention to Combat Desertification (UNCCD) is a legally binding international agreement aimed at addressing land degradation and desertification [87].

Overgrazing and drought in semi-arid regions makes soil susceptible to wind erosion. High dust levels in the air are evident in this photograph from Niger. High stocking densities, often the result of traditional practices but also due to changes in land tenure or the need to access water supplies, is a key driver of land degradation in dry areas. (JR/IRD)

How can shifting cultivation avert desertification?

Traditionally, a simple but effective farming system that took note of soil constraints, known as shifting cultivation, was practiced widely throughout Africa. Under shifting cultivation, the natural vegetation was cut at shoulder height to allow it to regenerate quickly. The cut branches were burned and the ash was added to the soil as a source of nutrients. In addition, a type of zero tillage was practiced as crops were planted in small holes, pits or furrows. A plot of land would be cropped for about three or four years at the most and allowed to revert to a 'natural' state before the soil showed signs of degeneration. The soil would remain fallow for about twenty years before it was considered ready for another cycle of cropping. Shifting cultivation is a sustainable agricultural practice that maximises soil fertility, minimises erosion and weeding and reduces the risk of crop failure. The soil was seen as a precious resource that should not be over-exploited. Land ownership issues today mean that the practice is limited and yields are unable to meet the needs of an exploding population.

Soil erosion

Erosion is the wearing away of the land surface by water and wind, primarily due to inappropriate land management, deforestation, overgrazing, forest fires and construction activities. In simple terms, erosion involves three basic steps that are common to both water and wind erosion: the detachment of soil particles by the impact energy of rain or wind, their subsequent transport and deposition in a new location. Erosion rates (usually measured in kg/ha/year) are very sensitive to soil texture and moisture, vegetation cover, land use, slope and climate (especially rainfall patterns, wind direction and strength) as well as to soil conservation practices at field level.

Soil erosion is a natural process but can be accelerated by human activities such as inappropriate cultivation practices, land clearance, overgrazing, construction on, or undercutting of, steep slopes and excessive footpath or vehicle use. Erosion has an impact on soil fertility due to disrupted nutrient cycles and in severe cases can lead to a total loss of the soil body. Erosion affects land use and land value and has negative effects on habitats and biodiversity.

Soil erosion has substantial off-site consequences as well. The soil removed by runoff, for example during a large storm, will create mudflows and accumulate below the eroded areas, in severe cases blocking roadways or drainage channels and inundating buildings. By removing the most fertile topsoil, erosion reduces soil productivity and, where soils are shallow, may lead to an irreversible loss of the entire soil body. Where soils are deep, the loss of topsoil may often not be conspicuous. Nevertheless, continued erosion may be potentially very damaging if no corrective action is taken (see Preventing Soil Erosion box on this page).

While there are no systematic assessments for Africa as a whole, soil erosion by water is pronounced in Northern Africa, Madagascar and South Africa.

Soil erosion by wind (aeolian erosion)

Aeolian erosion occurs when strong winds blow across dry soil on unprotected surfaces. As in water erosion, the wind detaches soil particles from the surface. Once detached the particles are transported to a new location. Wind erosion is particularly evident where annual rainfall is below 600 mm and the dry season lasts more than six months. The Sahel, the Mediterranean and parts of southern Africa are particularly affected. It is a major source of land degradation, can cause crop failure and has significant human health issues.

Three types of wind erosion are recognised:

- Suspension: Fine particles less than 0.1 mm in size are moved parallel to the surface then upward into the atmosphere by strong winds, returning to the ground only when the wind subsides or with precipitation. Suspended particles can travel thousands of kilometres.
- Saltation: Particles from 0.1 to 0.5 mm bounce short distances along the surface, dislodging additional particles with each impact. The bouncing particles, ranging in sizes, usually remain within 30 cm of the surface. This process accounts for 50 to 90% of the total movement of soil by wind.
- Soil Creep: Larger soil particles roll and slide along the ground surface, often aided by impacts of saltating particles.

Saharan winds

From November to March, a dry, southwesterly wind known as the **Harmattan**, blows large amounts of dust from the Sahara. In some West African countries, the amount of dust in the air can severely limit visibility, lower air quality and disrupt air travel for several days. However, the Harmattan can also be a significant source of soil nutrients.

The **Khamsin** (or khamaseen) is a dry, hot and dusty local wind that blows across North Africa from February to June. The Khamsin carries great quantities of sediment from the deserts, with wind speeds in excess of 100 km/h. Temperatures can rise by up to 20°C in a few hours. The wind is triggered by depressions moving eastwards along the southern parts of the Mediterranean.

The **Sirocco** (or *ghibli*) is strong wind which causes dusty conditions along the north African coast during the autumn and the spring. It causes storms in the Mediterranean and cool wet weather in Europe. Warm, dry, tropical air is pulled northward by low-pressure cells that move eastwards across the Mediterranean Sea. Many people attribute health problems to the Sirocco either because of the heat and dust in Africa or because of the dampness in Europe. The fine dust carried by the Sirocco winds can cause abrasion in mechanical devices and enter buildings.

Above: A stunning photograph of both sheetwash and rill erosion on a maize field in Kenya. The thin sheet of water flowing over the soil surface collects particles on the way. This is evident by the red colour of the water in this picture. Where the flow becomes concentrated, small channels or rills occur. Fine particles (i.e. clay or silt) can be carried a great distance before deposition. As most organic matter in mineral soils occurs in the upper part of the soil, the removal of topsoil can have a significant impact on soil fertility and water holding capacity. (BO)

Below: Gullies and bare ground on a hill slope in Kenya – clear signs of soil erosion by water. (BO)

Above: A satellite image of a dust storm over the coast of west Africa carrying particles from the Sahara, out over the Atlantic then northwards towards the Canary Islands. Dust from the Sahara is often deposited over Europe and can affect water turbidity in the Caribbean. (NASA)

Below: A wall of dust indicates an approaching sandstorm – a relatively common meteorological phenomenon in arid and semi-arid regions. Strong winds blow loose sand and dust from dry surfaces. Soil organic matter and nutrient-rich clay and silt particles are particularly susceptible. The storm front in this striking image, taken near Niamey in Niger in June 2010, is several hundred metres high. (BH/IRD)

Soil erosion by water

Soil erosion by water is one of the main factors limiting soil productivity and impeding agricultural enterprise in Africa, especially in the humid tropical regions where population pressure, deforestation and high rainfall, often in the form of torrential downpours, can lead to annual soil losses in excess of 50 t ha^{-1}.

When raindrops hit the soil surface, their impact can shatter aggregates into smaller pieces or displace individual particles laterally by up to 1 m. If the rainfall rate exceeds the rate at which water can infiltrate the soil, the excess water flows down the slope (i.e. as run off), carrying detached soil particles with it. Some particles float into holes or gaps in the soil surface which then become clogged and further reduce infiltration into the soil. As surface water velocity reduces, the energy needed to continue carrying the suspended sediment is lost causing the soil particles to be deposited in a new location.

Four types of water erosion are recognised:

- Splash Erosion: Direct movement of soil by the impact of raindrops. Soil particles can be displaced by up to 1 m.
- Sheet Erosion: Removal of a thin layer of soil from a large area which occurs when soil is saturated. Usually the first sign that erosion is occurring. Also known as sheetwash.
- Rill Erosion: Increased speed of sheet erosion leads to the formation of small channels or rills, often interconnected.
- Gully Erosion: Over time, rills can develop into large, wide channels. As a rule of thumb, a gully is so large that it cannot be smoothed out by conventional tillage.

Preventing soil erosion

Preventing soil erosion requires a combination of political, economic and technical considerations.

Politicians and decision makers need to address how soil is used on a national level and to identify areas that are at risk or vulnerable to erosion. Schemes could be established to offer incentives to farmers to manage their soil in a sustainable manner and implement practical measures to control soil erosion.

Technically, such measures could include:

- the use of contour ploughing (i.e. cultivating the land so that the plough furrows run at right angles to the slope) to restrict the initiation of rills and gullies;
- planting of hedges or tree belts that act as shelter belts and to reduce ground wind speeds;
- the use of terraces on sloping land;
- minimising the removal of natural vegetation, especially on slopes or even on flat terrain if wind erosion is an issue;
- strip cultivation - leaving unploughed vegetated strips between tilled land or allowing buffer zones of indigenous plants to grow along river banks;
- ensuring adequate plant cover in rainy, dry or windy periods, especially in the period immediately after ploughing;
- making sure that organic matter levels are maintained. Organic matter binds soil particles together and plays an important part in preventing erosion;
- avoiding overgrazing and the over-cultivation of crop lands.

Erosion control on steep land in East Africa through the construction of terraces. In addition to providing land for cultivation, terraces reduce surface runoff. (VL)

Soil sealing

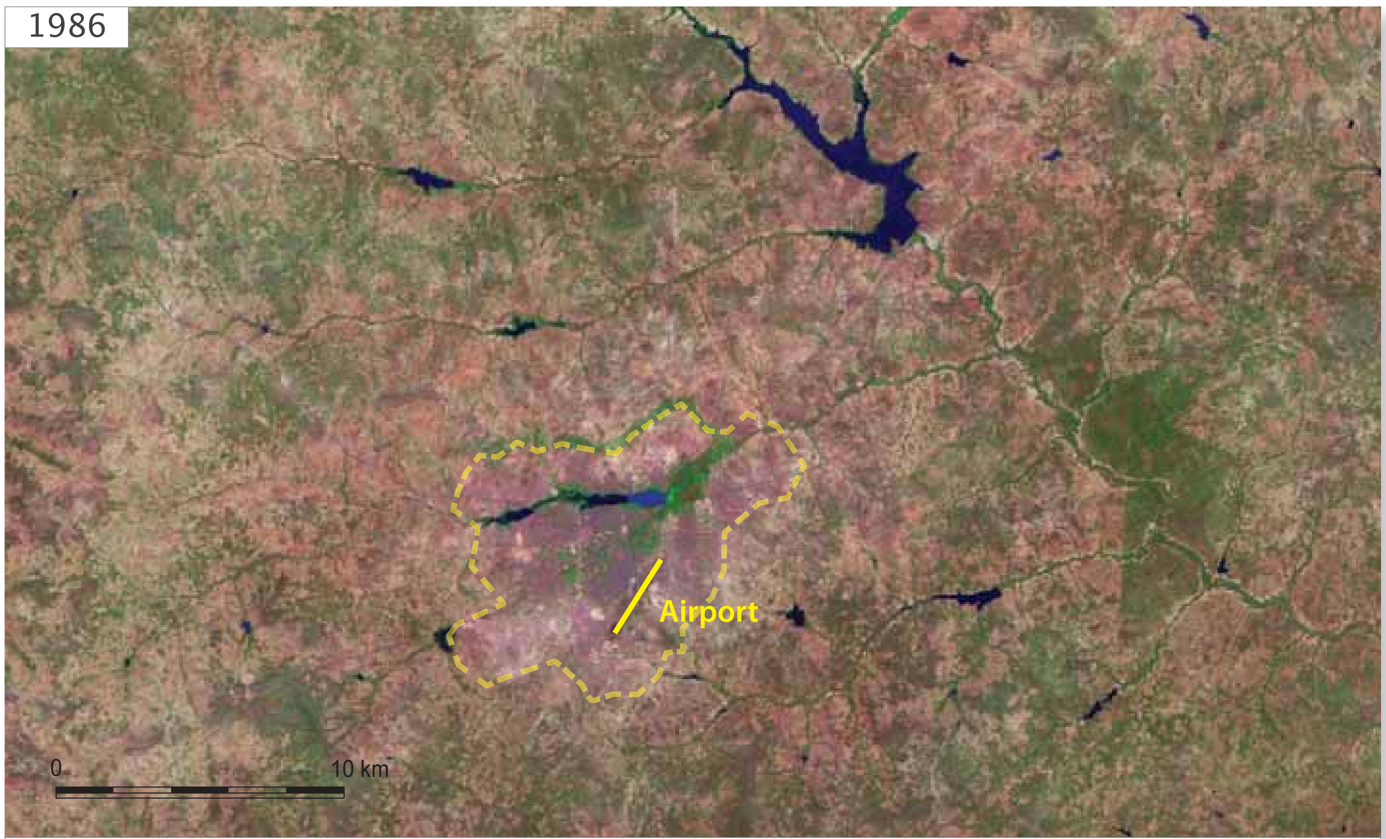
More than a third of Africa's 1 billion inhabitants currently live in urban areas. By 2030 that proportion will have risen to a half [88]. Such a trend will have significant impacts on soils. In the vicinity of urban areas, one of the main issues is soil sealing.

Sealed soils can be defined as the destruction or covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material (asphalt, concrete, etc.). It is the most intense form of land take and is essentially an irreversible process. Sealing also occurs within existing urban areas through construction on residual inner-city green zones. The sealing of soil surfaces, by covering them with buildings, roads and other developments, reduces the area available for soil to carry out most of its essential functions such as food production, filtering and absorbing rainwater (reducing surface run-off, flood control and replenishing groundwater) and providing a habitat for soil organisms. It should be noted that most urban areas were located initially close to fertile land and sources of water. For this reason, urban expansion very often consumes high quality agricultural soil at a time when food production needs to match demand.

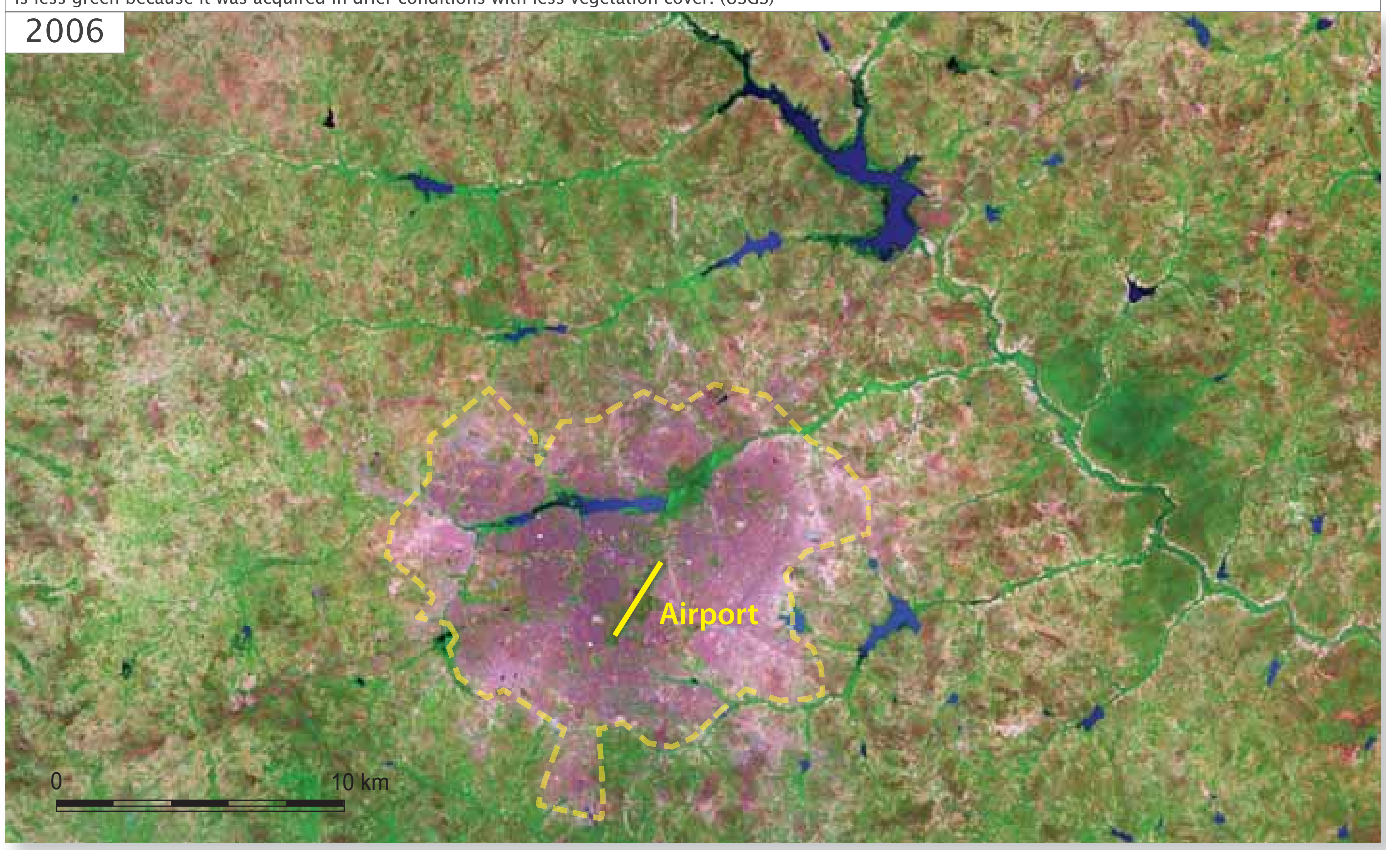
An associated issue of soil sealing is the increased risk of urban flooding. Sealed soils are unable to absorb rainfall. This increases both the volume and speed of run-off of rain water to the natural drainage system. Flood peaks develop much quicker leading to rivers bursting their banks and to drains being unable to cope with the flow of water. Over the last decades, the African continent has increasingly experienced severe flooding. In 2007 more than one million people were affected by flood events in Uganda, Ethiopia, Sudan, Burkina Faso, Togo, Mali and Niger. In 2000, a similar situation occurred in Mozambique, Zambia, Zimbabwe, Botswana, Madagascar and South Africa where a devastating flood left 1.25 million people homeless, hundreds dead and destroyed crops, livestock and major infrastructural facilities. With an increasingly urbanised population, such events are likely to be even more catastrophic in the future.

Urban development in Africa can take many forms ranging from modern, well-ordered, multi-story developments (**above**: centre of Ouagadougou in Burkina Faso (RZ)) to a more haphazard, piecemeal expansion along principal infrastructure routes (**below**: downtown Monrovia in Liberia. (PDI)

Flooding in Ouagadougou during September 2009 as a result of an exceptional rainfall of 300 mm in 10 hours. Extensive soil sealing was seen as a major factor. (AN/IRD)



The image **above** shows a view from space of Ouagadougou, the capital city of Burkina Faso, as captured by the NASA Landsat satellite. In this false-colour image, vegetation appears bright green, bare or sparsely vegetated ground is beige to grey-green, water bodies are blue while paved surfaces and buildings appear pink and purple. The image **below** shows the corresponding scene in 2006. The later image (2006) shows that urbanisation has spread out from the city centre, especially to the east and south while becoming much denser within the urban area. In both images, Ouagadougou airport appears as a diagonal line near the centre of the image. In 1986, the airport lay fairly close to the city's outskirts while in 2006, the airport is surrounded by urban development. Between 1960 and 1993, Ouagadougou experienced a 14-fold increase in area due to a huge migration of the rural population to towns that led to a proliferation of unplanned settlements. It should be noted that most urban areas were located initially close to fertile land and sources of water. Very often, urban expansion consumes high quality agricultural soil at a time when food production needs to match demand. Both images are at the same scale and show the same extents. The 1986 image is less green because it was acquired in drier conditions with less vegetation cover. (USGS)



Preventing soil sealing

Soil sealing must be addressed nationally and at a local level by managing urban development and through the inclusion of mitigation measures. Maintaining key functions such as the natural drainage and filtering capacity of soils to slow the passage of water to rivers, thereby reducing pollution and flooding risk, should be a priority for urban planners. In particular, specific attention should be placed on:

- raising awareness of politicians, decision-makers, planners and residents about the value of soil in general and especially in an urban context;
- the development of planning guidelines where a preference is given for urban redevelopment (this is also referred to as brownfield development) rather than consumption of agricultural or environmentally productive soils;
- using permeable materials for walkways and parking zones (e.g. gravel, concrete or plastic grids, block surfaces with drainage holes) instead of creating an impermeable surface made out of cement or asphalt.

A map showing an index of accessibility for Africa based on travelling time to cities with more than 50 000 inhabitants. The model takes into account infrastructure development and, as such, is a good proxy for soil sealing. The main urban agglomerations are shown in red while the bright tones indicate areas within four hours travelling. While the map does not show actual sealing, the image gives a sense of where human activity is concentrated across the continent and the pattern of the principal road network along which urbanisation takes place. The grey areas indicate remoter (i.e. less developed) regions. The data show that many parts of Africa (e.g. the Sahara, Kalahari, parts of the Congo Basin, the Horn of Africa) are classed as very inaccessible. (JRC) [89]

Soil pollution

Contaminated land

In many parts of Africa, there is a substantial legacy of land that has been contaminated by a range of toxic chemicals in the soil. These contaminants may include metals, hydrocarbons and other organic pollutants, pathogens and substances that are harmful to both humans and the environment generally. Contaminants introduced into the soil can result in the decline or loss of ecosystem services provided by soil. When industrial land becomes polluted, there may be a risk to human health and ecology through contaminated vegetation (e.g. root crops), groundwater and surface water if there is run-off or leaching. The level of contamination may be a deterrent to future development putting increased pressure on other land.

Poor management of industrial areas and waste disposal sites, inadequate effluent and emission controls, the importing and storage of waste materials (often toxic) and a lack of education in the use and disposal of chemicals and waste products are key factors. Unfortunately, the extent of contaminated land across Africa is essentially unknown.

Contaminated sites: an alternative view!

While the remediation of polluted sites should be the priority, some contaminated land may support habitats and species of high conservation value. Many sites may also have cultural and archaeological importance and may need to be protected for these purposes. The Big Hole diamond mine in South Africa is now being developed as a tourist attraction.

However, much care must be taken to minimise any eventual impact on human health and the environment.

Above: Manual application of pesticide on a cotton crop in Benin. (PS/IRD)

Below: There are numerous documented cases of environmental problems caused by the mining of metals and metallurgical activities in African countries. In many localities the concentrations of elements such as copper, zinc, cadmium, lead and arsenic are several orders of magnitude higher than the limits set by the UN World Health Organization (WHO). Humans can be exposed to heavy metals by drinking water leaching through waste tips and inhaling air or soil contaminated by mining activities and the associated processing chains (e.g. ore smelting). Limited environmental protection legislation or controls are common factors in many parts of Africa, particularly in legacy sites, that have been abandoned. (OS)

Diffuse soil contamination

Diffuse pollution is distinct from the local contamination of soil which originates from clearly defined sources. Diffuse pollution is typically linked to atmospheric deposition, particular farming practices and inappropriate waste recycling and treatment.

- Pollution from atmospheric deposition is due to emissions from industry, transport and agriculture. Soils are exposed to acidifying contaminants (sulphur dioxide, nitrogen oxides, and ammonia), heavy metals and man-made organic compounds. The Chernobyl accident in 1986 and global fall out from nuclear weapons testing have resulted in widespread radioactive caesium contamination in soils. Deposition of ammonia and nitrogen deposition from transport, industry and agriculture also result in unwanted nutrient enrichment and lead to a decline in biodiversity and habitats.
- A number of farming practices can also be regarded as a source of diffuse pollution. Nutrient imbalances in soil from fertiliser use can lead to contamination of ground and surface water. Soil erosion is also a significant source of diffuse water pollution and there are concerns relating to heavy metal accumulations.
- In some areas, sewage sludge, the solid fraction from wastewater treatment sites, is spread on the land. While it provides nutrients for plants and organic matter as a soil conditioner, sewage sludge can contain elevated levels of heavy metals and microorganisms that could pose a threat to human health.

Growing wheat in the Sahara

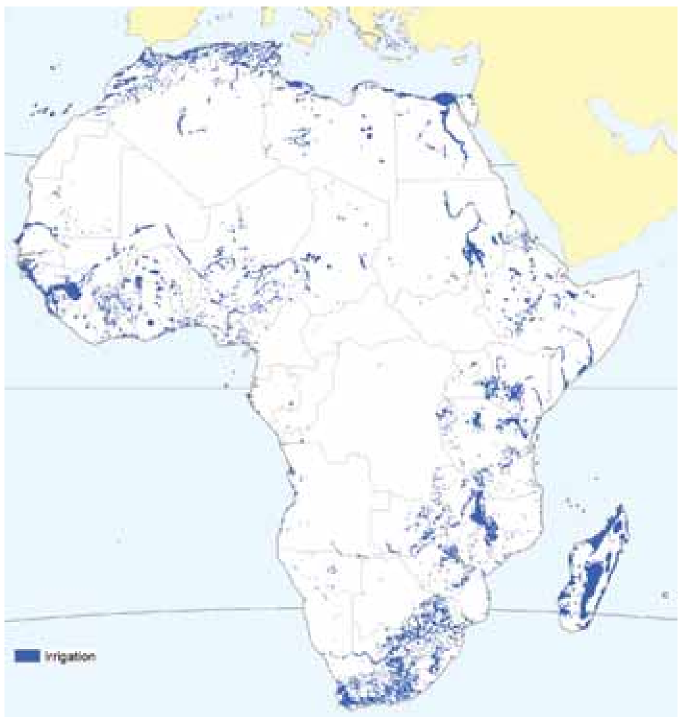
Even in the middle of the Sea of Sand Desert in southeastern Libya (**top**, Google Earth), wheat can be grown in pivot irrigation plots (middle, Google Earth/CNES/Spot Image 2013). The use of 'fossilised' water for irrigation can support agriculture in even the most inhospitable locations (e.g. Al Kufrah, Libya; bottom, USDA). However, the evaporation of water can lead to salt accumulation in the root zone and large amounts of energy are required to extract the water, especially from deep aquifers (see page 21).

Salinisation

The accumulation of salt in soil is known as salinisation. While the atlas has shown that naturally saline soils occur in many parts of Africa, salinisation in the context of this section is concerned with the increase in salt content in soils resulting from human interventions such as inappropriate irrigation practices, the use of salt-rich irrigation water and/or poor drainage conditions. [90]

Long-term irrigation causes salinity as almost all water contains some level of dissolved salts. When plants use water, the salts are left behind in the soil and over time begin to accumulate. In addition, application of water at the wrong time can cause it to evaporate leaving salts to form on the bare surface. These can then be carried into the soil by the next input of water.

Elevated salt levels in soil limit the agricultural or ecological potential of the affected land and represent a considerable threat to sustainable development. Salts can cause harm to plant life and affect soil fertility, leading to a reduction in agricultural productivity and biomass yield. While saline soils often support a distinctive natural ecosystem, a build up of saline conditions in the soil can lead to a collapse of the indigenous vegetation community. High salt levels can affect the numbers, diversity and function of soil biota, which limit various soil functions and, in turn, can lead to soil degradation and possibly the onset of desertification.



Map showing the principal areas where irrigation is used to support the growth of crops. Care must be taken in many of these areas to limit the build up of salts in the soil. (FAO/JRC) [91, 91a]

Manual irrigation of horticulture on coastal Arenosols near Lome, Togo. Soil must be flushed regularly with valuable irrigation water to remove the build up of salts. (JD)

Preventing salinisation

The primary methods of controlling soil salinity are:

- to use excess water to flush the salts from the soil. In most areas where salinisation is a problem, this must inevitably be done with high quality or scarce irrigation water;
- to limit the use of saline or brackish water in irrigation;
- to minimise evaporation, do not over-water and do not irrigate in full sun.

Salt in soil – understanding the terminology

Salinity - presence of water-soluble salts;

Alkalinity - high soil pH;

Sodicity - high levels of sodium (Na).

Compaction and landslides

Soil compaction

Soil compaction is a form of physical degradation due to the reorganisation of soil micro- and macro-aggregates, which are deformed or even destroyed as a result of pressure on the surface of the soil. Compaction leads to a reduction in biological activity, nutrient uptake, porosity and permeability. Compaction can affect water infiltration capacity and increase erosion by accelerating runoff. A feature of compacted soils is the formation of a pan-layer that is less permeable for roots, water and oxygen than the soil below and is a bottleneck for the functioning of the subsoil. Compaction is particularly evident across the Sahel, South Africa and Zambia.

Topsoil compaction occurs when soil is subjected to surface pressure from the passage of heavy machinery or by repeated trampling of grazing animals, especially under wet conditions. In arable land with annual cultivation, subsoil compaction is caused by tractors driving directly on the subsoil during ploughing, by the design of the plough or from very heavy axle load weights being transmitted deep in to the soil. Unlike topsoil, the subsoil is not loosened annually, and compaction becomes cumulative. As it occurs below the ground, soil compaction is very much a hidden problem. In addition, compaction reduces the stability of soil and can increase the risk of erosion. In irrigated areas, compaction can lead to poor water use efficiency and increased costs (i.e. more water is needed).

Preventing soil compaction

The risk of soil compaction can be lessened by:

- avoiding heavy pressures on land, especially when the soil is wet;
- reducing stocking densities of animals;
- use of low-pressure tyres or higher number of axles on farm machinery;
- use of minimum-tillage technology;
- addition of organic matter.

Soil compaction can be remediated by tillage or ripping the soil.

Subsoil compaction can only be countered by deep tillage which breaks through plough pans. However, the effects of deep tillage are usually short lived unless management strategies are adopted to avoid further compaction.

Above: Topsoil compaction can be treated by breaking up the soil with a fork, spade or a rotary hoe. Subsoil compaction may require specialised technology such as this powerful soil ripper that is pulled through the soil by a tractor. Care must be taken not to re-compact the soil. (EP)

Below: Map showing the extent of soils vulnerable to compaction. The FAO estimate that 18 million ha are compacted in Africa. (GLASOD/JRC) [75]

Landslides

A landslide is the gravitational movement of a mass of rock, debris or soil down a slope. Landslides occur when the condition of a slope changes from being stable to being unstable. Such changes can be caused by a range of triggering factors, acting together or alone. Landslides are usually classified on the basis of the type of material involved (rock, debris, earth, mud) and the type of movement (fall, topple, slide, flow, spread). Landslides can be slow moving or very rapid.

Natural causes of landslides include intense rainfall, prolonged periods of wet weather or snowmelt, earthquakes, volcanic activity, loss of vegetation cover (e.g. after wildfires), earthquakes (e.g. Madagascar, 2012) and the undercutting of slopes by rivers or ocean waves. Anthropogenic activities include deforestation and removal of vegetation cover, inappropriate agricultural practices and infrastructure construction such as slope cutting and loading.

Landslides occur more frequently in areas with steep slopes and highly erodible soils, clayey subsoils or weathered and jointed bedrock, usually following intense and prolonged precipitation or earthquakes.

Landslides threaten soil functions in two ways:

1. removal of soil from its in situ position; and
2. covering the soil downslope from the area where the slope has 'failed'.

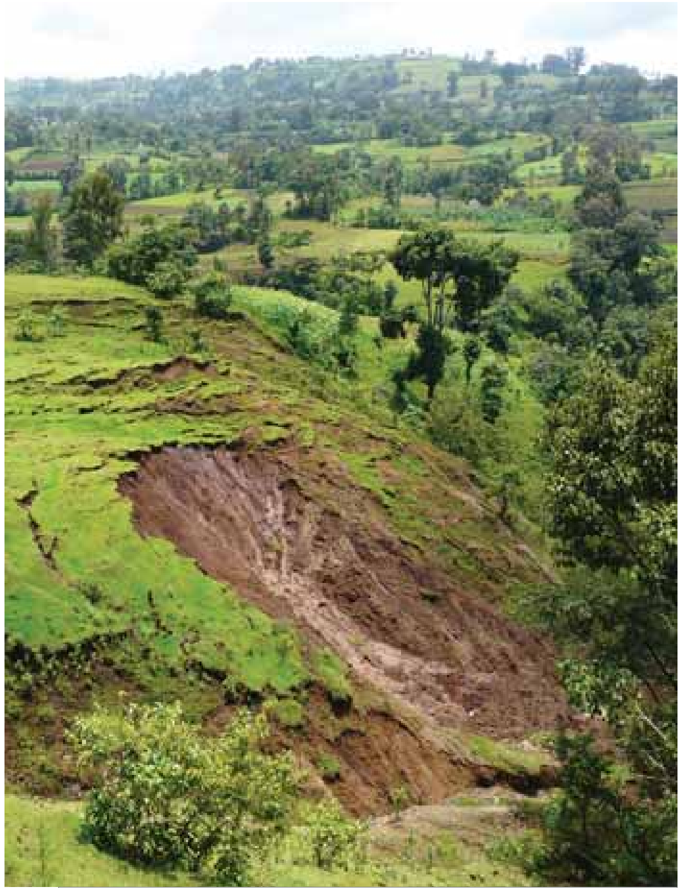
Where a landslide removes all soil material, all soil functions will be lost and weathering processes of the hard rock or sediment now exposed at the surface need to operate for hundreds if not thousands of years to produce enough material for soil functions to resume. When only a part of the soil profile (e.g. the A horizon) is removed by a landslide, some soil functions may remain, although most are likely to be impaired.

Landslides are a major hazard in most mountainous and hilly regions as well as in steep river banks and coastlines. Their impact depends mainly on their size and speed, the elements at risk in their path and the vulnerability of these elements. This problem is particularly acute in Africa where less adaptable populations (e.g. those constrained by poverty, land availability) are much more vulnerable to geohazards. Every year landslides cause fatalities and result in significant damage to infrastructure (roads, railways, pipelines, artificial reservoirs, etc.) and property (buildings, agricultural land, etc.). Landslides can also affect mine waste tips, tailing dams and landfills, causing fatalities and contaminating soils, surface water and groundwater.

A positive aspect of landslides is that they are a major provider of sediments and nutrients for floodplain soils.

Given the generally level landscape and dryness of the African continent, landslides are not a widespread hazard. The primary regions of occurrence and potential in Africa are mountain ranges such as the Atlas Mountains, the Ethiopian Highlands, the East African Rift, the mountainous and hilly regions of Southern Africa, and landslide-sensitive geological formations such as volcanic slopes. Madagascar and smaller islands like in Cape Verde and the Canaries also experiences all types of landslides.

However, information on landslides is far more limited in Africa compared to other continents. There are very few data at the continental and regional scale and it is difficult to have a clear picture of the total area affected. Local estimates have been made for regions of the Democratic Republic of the Congo, Rwanda, Burundi, Uganda, Kenya, Tanzania, Ethiopia, Cameroon, Nigeria, Algeria, Morocco, Zambia and South Africa for instance. The UN WHO have also prepared an assessment of landslide risk for Africa. [92a].



A landslide in Nitisols in Ethiopia. Note the tension cracks in the soil beyond the landslide scar. Such features are potential early-warning signs that a possible landslide could be triggered in the near future due to intense rainfall or land clearance. (EVR)

Landslide activity and impact are expected to increase in the future in response to increased urbanisation and development in landslide-prone areas, deforestation and the associated changes in land use and land cover, and the changing climate conditions (higher or more intense rainfall patterns). However, due to the lack of pan-African data, trends in landslide distribution and impacts are difficult to evaluate.

The aftermath of a large landslide on the slopes of Mount Elgon in Uganda that occurred in June 2012. The landslide appears to have been a quite mobile flow in deeply weathered residual soil and was triggered by intense rainfall. The Mount Elgon area is prone to landslides partly as a result of deforestation on its coffee-producing slopes [92]. The landslide destroyed three villages and led to the deaths of dozens of people. Despite the elevated risk of landslides in the region, there is great resistance amongst the local people to relocation due to the presence of fertile soil and a low incidence of malaria. (JD)

Key soil issues for African countries

Algeria

Northern Africa, bordering the Mediterranean Sea, between Morocco and Tunisia - largest country in Africa; Climate is arid to semi-arid; Terrain is mostly high plateau and desert, some mountains - lowest point: Chott Melrhir -40 m, highest point: Mt. Tahat 3 003 m; Arable land: 3%; Main soil types: Arenosols, Calcisols, Leptosols, Luvisols and Regosols; Key issues are soil erosion, overgrazing, salinisation, desertification, industrial pollution and fertiliser runoff.

Angola

Southern Africa, bordering the South Atlantic Ocean, between Namibia and DR Congo; Climate is semi-arid in south and along coast, north has cool, dry season and hot, rainy season; Terrain is narrow coastal plain rising abruptly to vast interior plateau; Arable land: 3%; Overuse of pastures and subsequent soil erosion attributable to population pressures is widespread; Main soil types are Acrisols, Arenosols, Ferralsols, Gleysols, Lixisols and Nitisols; Key issues are desertification and deforestation of tropical rain forests in response to both international demand for tropical timber and to domestic use as fuel results in a loss of biodiversity and soil erosion (the latter contributes to water pollution and siltation of rivers and dams).

Benin

Western Africa, between Nigeria and Togo; Northern regions have a marked dry season while the south has an equatorial climate; Terrain is mostly flat to undulating plain, some hills and low mountains; Arable land: 24%; Main soil types are Acrisols, Alisols, Lixisols and Plinthosols; Key issues are erosion associated with harmattan wind and desertification in the north. Deforestation is a concern in the south.

Botswana

Southern Africa, north of South Africa, landlocked; Climate is semi-arid, warm winters and hot summers; Terrain is predominantly flat to gently rolling tableland with Kalahari Desert in the southwest; Arable land: 1%; Main soil types are Arenosols, Gleysols, Histosols, Lixisols and Solanchaks; Key issues are overgrazing, desertification, periodic droughts and wind erosion (seasonal winds from the west carry sand across the country).

Burkina Faso

Western Africa, north of Ghana, landlocked; Climate is tropical with warm, dry winters and hot, wet summers; Terrain is mostly flat or dissected, undulating plains with hills in the west and southeast; Arable land: 18%; Main soil types are Arenosols and Lixisols; Key issues are recurring droughts and desertification which severely affect agricultural activities, population growth, overgrazing, land degradation and deforestation.

Burundi

Central Africa, east of DR Congo, small, landlocked country; Climate is equatorial, average annual temperature varies significantly with altitude; Terrain is hilly and mountainous, dropping to a plateau in east; Arable land: 36%; Main soil types are Acrisols, Ferralsols and Nitisols; Key issues are soil erosion from overgrazing and the expansion of agriculture into marginal lands, landslides, drought, flooding, deforestation (little forested land remains because of uncontrolled cutting of trees for fuel) and loss of biodiversity.

Cameroon

Central Africa, on the Gulf of Guinea, between Equatorial Guinea and Nigeria (often referred to as Africa in miniture); Climate varies with terrain, from equatorial along the coast to semi-arid and hot arid in the north; Terrain is diverse, with coastal plains in southwest, a dissected plateau in centre, mountains in the west and dry plains in the north. At 4 095 m, the volcanic massif of Mt. Cameroon is one of Africa's highest peaks; Arable land: 13%; Main soil types are Acrisols, Alisols, Ferralsols, Gleysols, Lixisols, Nitisols and Planosols; Key issues are deforestation, overgrazing and desertification.

Cape Verde

Western Africa, a group of islands in the North Atlantic, west of Senegal; Climate is temperate with warm, dry summers. However, precipitation is meagre and erratic; Terrain is steep, rugged and rocky with active volcanic landscape; Arable land: 11%; Main soil types are Andosols, Calcisols and Leptosols; Key issues are prolonged droughts; seasonal harmattan wind producing obscuring dust, soil erosion, deforestation due to demand for fuel wood, water shortages, desertification and loss of biodiversity.

Central African Republic

Central Africa, north of Democratic Republic of the Congo, landlocked; Climate is tropical with hot, dry winters and mild to hot, wet summers; Terrain is mostly flat to rolling, monotonous plateau with some scattered hills in the northeast and southwest; Arable land: 3%; Main soil types are Acrisols, Ferralsols, Lixisols, Nitisols and Plinthosols; Key issues are hot, dry, dusty harmattan winds that affect northern areas, desertification and deforestation while floods are common.

Chad

Central Africa, south of Libya; Climate is tropical in the south, desert in the north; Terrain is broadly arid plains in the centre, desert in the north, mountains in the northwest (> 3 000 m) and lowlands in the south; Arable land: 3%; Main soil types are Arenosols, Fluvisols, Leptosols and Vertisols; Key issues are hot, dry, dusty harmattan winds that occur in north, periodic droughts, soil pollution in rural areas due to improper waste disposal and desertification.

Comoros

Southern Africa, group of islands at the northern mouth of the Mozambique Channel, about two-thirds of the way between northern Madagascar, one of the smallest countries in Africa; Climate is tropical maritime with a marked rainy season (November to May); Terrain is volcanic, steep mountains to low hills; Arable land: 36%; Main soil types are Andosols, Ferralsols, Leptosols and Nitisols; Key issues are deforestation, soil degradation and erosion due to cultivation on slopes without proper terracing.

Congo, Democratic Republic of

DR Congo is the second largest country in Africa, located at the heart of sub-Saharan Africa, almost entirely landlocked, between the Republic of the Congo, Central African Republic, South Sudan, Uganda, Rwanda, Burundi, Tanzania, Zambia and Angola; Climate is tropical, hot and humid in the vast Congo river basin, cool and dry in the southern highlands, cool-cold and wet in the eastern highlands; Arable land: 3%; Main soil types are Acrisols, Arenosols, Cambisols, Ferralsols, Gleysols and Lixisols; Key issues are deforestation, mining of minerals causing environmental damage and water pollution, soil erosion and seasonal flooding.

Congo, Republic of the

Central Africa, bordering the South Atlantic, astride the Equator between Angola and Gabon; Climate is tropical with persistent high temperatures and humidity. Distinct rainy (March to June) and dry season (June to October); A coastal plain leads to a northern and southern basin separated by a central plateau; Arable land: 1.5%; Main soil types are Acrisols, Arenosols, Ferralsols, Gleysols and Nitisols; Key issues are seasonal flooding along the main river systems and deforestation.

Côte d'Ivoire

Western Africa, bordering the North Atlantic, between Ghana and Liberia; Equatorial climate in the south grades to semi-arid in the far north; A coastal plain and plateau are separated by central mountains; Arable land: 10%; Main soil types are Acrisols, Alisols, Lixisols and Plinthosols; Key issues are torrential flooding in the rainy season and deforestation (most of the country's forests - once the largest in West Africa - have been heavily logged).

Djibouti

Eastern Africa, bordering the Gulf of Aden and the Red Sea, between Eritrea and Somalia; Climate is arid to semiarid; Terrain is mostly high plateau and desert; some mountains. Lake Assal is the lowest point in Africa (155 m below sea level) and the saltiest lake in the world; Arable land: < 1%; Main soil types are Fluvisols, Gypsisols, Leptosols and Solonchaks; Key issues are earthquakes, droughts, occasional cyclonic disturbances from the Indian Ocean bringing heavy rain and flash floods, volcanic activity, limited fertile soils and desertification.

'Soil' in Africa

It is estimated that there are more than 1 500 distinct languages throughout Africa. Therefore, it would take a large book just to list all the indigenous words for soil! However, some of the most common are: Swahili = udongo; Zulu = urahlabati; Arabic = turaabun; Creole = du; Xhosa = ngcolisa; Afrikaans = grond; French = sol.

Egypt

Northern Africa, bordering the Mediterranean and the Red Sea, between Libya and Israel, north of Sudan, includes the Sinai Peninsula; Climate is desert with hot, dry summers with moderate winters; Terrain is vast desert plateau interrupted by Nile valley and delta - Qattara Depression is 133 m below sea level; Arable land: 3%; Main soil types are Arenosols, Calcisols, Leptosols and Regosols; Key issues are desertification, periodic droughts, flash flood, landslides, wind erosion causes dust and sand storms. Large amounts of agricultural soils are being lost to urbanization and windblown sands. Increasing soil salinisation below Aswan High Dam. Soil pollution from agricultural pesticides and industrial effluents. Rapid growth in population which is overstraining natural resources.

Equatorial Guinea

Central Africa, bordering the Gulf of Guinea, between Cameroon and Gabon; Climate is always hot and humid; Terrain characterised by coastal plains rising to interior hills (> 3 000 m), volcanic islands offshore; Arable land: 5%; Main soil types are Acrisols, Ferralsols and Nitisols; Key issues are wind erosion, flash floods with associated erosion or landslides and deforestation.

Eritrea

Eastern Africa, bordering the Red Sea, between Djibouti and Sudan; Along the Red Sea coast the climate is hot and dry (Danakil Depression is one of the hottest places in Africa), cooler and wetter in the central highlands (around 600 mm of rainfall annually), semi-arid in western hills and lowlands; Terrain is dominated by the extension of the Ethiopian highlands, descending eastwards to a coastal desert plain, on the northwest to hilly terrain and on the southwest to flat-to-rolling plains. Elevation ranges from -75 m to over 3 000 m; Arable land: 5%; Main soil types are Cambisols, Fluvisols, Leptosols and Lixisols; Key issues are frequent droughts, deforestation, overgrazing and soil erosion leading to marked desertification in places.

Ethiopia

Eastern Africa, west of Somalia, landlocked; Climate is tropical monsoon with marked variations induced by topography (Danakil Depression is one of the hottest places in Africa); Terrain is a high plateau with central mountain range divided by Great Rift Valley. Elevation ranges from -125 m (Danakil Depression) to over 4 500 m. Lake Tana is source of the Blue Nile; Arable land: 10%; Main soil types are Cambisols, Calcisols, Leptosols, Lixisols, Nitisols and Vertisols; Key issues are the geologically active Great Rift Valley, frequent droughts, deforestation, overgrazing, soil erosion, desertification and poor land management. Coffee, grain sorghum and castor bean are believed to have originated in Ethiopia.

Gabon

Central Africa, bordering the Atlantic at the Equator, between Republic of the Congo and Equatorial Guinea; Climate is tropical, always hot and humid; Terrain is a narrow coastal plain leading to a hilly interior with savannah in the east and south; Arable land: 1%; Main soil types are Acrisols, Arenosols, Ferralsols and Nitisols; Deforestation is the main issue affecting soils.

Gambia, The

Western Africa, bordering the North Atlantic and enclosed by Senegal – smallest country on the continent of Africa; Climate is tropical with hot, rainy season (June to November) and cooler, dry season (November to May); The country is essentially the flood plain of the Gambia River flanked by low hills. Highest point is only 53 m above sea level; Arable land: 28%; Main soil types are Acrisols, Fluvisols, Lixisols and Regosols; Key issues are drought (rainfall has dropped by 30% in the last 30 years), deforestation and desertification.

Ghana

Western Africa, bordering the Gulf of Guinea, between Côte d'Ivoire and Togo; Climate is tropical, warm and comparatively dry along southeast coast, hot and humid in southwest and hot and dry in north; Terrain is mostly low plains with dissected plateau in the south-central region; Arable land: 18%; Main soil types are Acrisols, Alisols, Lixisols and Plinthosols; Key issues are dry, dusty, northeastern harmattan winds from January to March, recurrent droughts (especially in the north which severely affect agricultural activities), deforestation, overgrazing, soil erosion and loss of biodiversity. Lake Volta is the world's largest artificial lake by surface area (8 482 km^2).

Guinea

Western Africa, bordering the North Atlantic, between Guinea-Bissau and Sierra Leone; Climate is generally hot and humid with monsoonal-type rainy season (June to November) with southwesterly winds and dry season (December to May) with northeasterly harmattan winds; Terrain is generally flat coastal plain rising to hilly and mountainous interior – source of the Niger River; Arable land: 4%; Main soil types are Acrisols, Alisols, Cambisols, Leptosols and Plinthosols; Key issues are deposition of wind-blown sediments, deforestation, desertification, soil contamination and erosion, overpopulation in forest regions and soil pollution as a result of poor mining practices.

Guinea-Bissau

Western Africa, bordering the North Atlantic, between Guinea and Senegal; Climate is tropical, generally hot and humid with monsoonal-type rainy season (June to November) with southwesterly winds. Dry season (December to May) with northeasterly harmattan winds. Terrain is mostly low coastal plain with mangrove swamps, rising to low savannah in the east; Arable land: 8%; Main soil types are Acrisols, Fluvisols, Lixisols and Plinthosols; Key issues are dust deposition by harmattan, brush fires, deforestation, soil erosion and overgrazing.

Kenya

Eastern Africa, bordering the Indian Ocean, between Somalia and Tanzania; Climate varies from equatorial along the coast to arid in the north; Low plains rise to central highlands which are cut by the Great Rift Valley. A fertile plateau dominates the west. Mount Kenya is 5 199 m above sea level and has glaciers; Arable land: 8%; Main soil types are Calcisols, Cambisols, Lixisols, Luvisols and Solonetz; Key issues are recurring drought, flooding during the rainy seasons, pollution from urban and industrial wastes, increased use of pesticides and fertilisers, deforestation, soil erosion and desertification. The Kenyan Highlands are one of the most successful agricultural production regions in Africa.

Lesotho

Southern Africa, surrounded by South Africa, landlocked; Climate is temperate with cool to cold, dry winters and hot, wet summers. The terrain is mostly highland with plateaus, hills and mountains – more than 80% of the country is above 1 800 m in elevation (max. 3 482 m); Arable land: 11%; Main soil types are Leptosols, Planosols and Regosols; Key issues are periodic droughts, population pressure forcing settlement in marginal areas which results in overgrazing, severe soil erosion and soil nutrient depletion.

Liberia

Western Africa, bordering the North Atlantic Ocean, between Côte d'Ivoire and Sierra Leone; Climate is hot, humid tropical - winters are dry with hot days and cool to cold nights while summers are wet, cloudy with frequent heavy showers; Coastline is characterised by lagoons, mangrove swamps, and river-deposited sandbars. A flat or gently rolling coastal plain rises to a grassy rolling plateau the supports limited agriculture, low mountains in northeast; Arable land: 3%; Main soil types are Acrisols, Ferralsols and Nitisols; Key issues include the dust-laden harmattan winds that blow from the Sahara (December to March), tropical rain forest deforestation, soil erosion and loss of biodiversity.

Libya

Northern Africa, bordering the Mediterranean Sea, between Tunisia and Egypt, very large country; Climate is Mediterranean along the coast but grades very quickly inland to a dry, extreme desert (more than 90% of the country is desert or semi-desert; Terrain is mostly barren, flat to undulating plains, plateaus and depressions (-47 m); Arable land: 3% - although fossil groundwater supports irrigation in the desert; Main soil types are Arenosols, Calcisols, Gypsisols, Leptosols and Solonchaks; Key issues are hot, dry, dust-laden winds in the spring and autumn dust and sandstorms, limited rainfall and desertification.

Madagascar

Southern Africa, island in the Indian Ocean (fourth-largest island in the world), east of Mozambique; Climate is hot and humid along the coast, a little cooler inland and arid in south; The terrain is a narrow coastal plain and a high plateau with mountains in centre; Arable land: 5%; Main soil types are Acrisols, Arenosols, Ferralsols, Fluvisols, Lixisols and Nitisols; Key issues are soil erosion as a result of extensive deforestation and overgrazing and desertification

Malawi

Southern Africa, east of Zambia, west and north of Mozambique, landlocked; Climate is cool-tropical with rainy season (November to May) and dry season (May to November); Terrain is narrow elongated plateau with rolling plains, rounded hills and some mountains (> 3 000 m). Lake Nyasa is almost 600 km long; Arable land: 3%; Main soil types are Acrisols, Ferralsols, Fluvisols, Leptosols, Nitisols and Vertisols; Key issues are deforestation, land degradation and the disposal of industrial wastes.

Mali

Western Africa, southwest of Algeria, north of Guinea, Côte d'Ivoire and Burkina Faso, west of Niger, landlocked; Climate is subtropical to topical and arid; Terrain is mostly flat with rolling northern plains covered by sand with savannah in the south and rugged hills in northeast; Arable land: 4%; Main soil types are Arenosols, Calcisols, Cambisols, Leptosols, Lixisols and Plinthosols; Key issues are flooding, deforestation, soil erosion and desertification.

Mauritania

Western Africa, bordering the North Atlantic, between Senegal and Western Sahara; Climate is sub-tropical and arid, constantly hot, dry and dusty; Terrain is mostly barren, flat plains of the Sahara, some central hills; Arable land: <1%; Main soil types are Arenosols, Leptosols, Regosols and Solonchaks; Key issues are hot, dry, dust/sand-laden sirocco wind and periodic droughts. Over-grazing, deforestation and soil erosion, aggravated by drought, are contributing to desertification. Limited rainfall.

Mauritius (and Reunion)

Southern Africa, volcanic islands in the Indian Ocean, east of Madagascar – very small; Climate is hot and humid, southeast trade winds give warm, dry winters (May to November) and hot, wet, humid summers (November to May); Terrain is a small coastal plain rising to discontinuous volcanic mountains; Arable land: 50%; Main soil types are Andosols, Leptosols, Nitisols and Umbrisols; Key issues include cyclones that trigger erosion events especially after land cover change.

Morocco

Northern Africa, bordering the North Atlantic and the Mediterranean, between Algeria and Western Sahara; Climate is Mediterranean, becoming more arid and hot towards the interior; Northern coast and interior are mountainous (>4 000 m) with large areas of bordering plateaus and inter-montane valleys. Coastal plains are fertile; Arable land: 19%; Main soil types are Calcisols, Cambisols, Leptosols, Luvisols and Vertisols; Key issues are land degradatio, urbanisation and p desertification (soil erosion resulting from farming of marginal areas, overgrazing, destruction of vegetation cover).

Mozambique

Southeastern Africa, bordering the Mozambique Channel, between South Africa and Tanzania; Climate is hot and humid. Terrain is mostly coastal lowlands, uplands in the centre with high plateaus in northwest and mountains in west; Arable land: 5%; Main soil types are Arenosols, Lixisols, Solonchaks and Solonetz; Key issues are severe droughts, devastating cyclones and floods in central and southern provinces, population migration to urban and coastal areas with adverse environmental consequences and desertification.

Namibia

Southern Africa, bordering the South Atlantic, between Angola and South Africa; Climate is hot and dry, rainfall is sparse and erratic; Terrain is mostly high plateau with the Namib Desert along coast and the Kalahari Desert in the east; Arable land: 1%; Main soil types are Arenosols, Calcisols, Gypsisols, Leptosols and Regosols; Key issues are prolonged periods of drought, land degradation and desertification.

Niger

Western Africa, southeast of Algeria, landlocked; Climate is mostly hot, dry and dusty with more humid conditions in the extreme south – one of the hottest countries in Africa; Terrain is predominately desert plains and sand dunes (80%) with flat to rolling plains in the south and hills in the north; Arable land: 11%; Main soil types are Arenosols, Calcisols, Cambisols, Fluvisols, Leptosols and Lixisols; Key issues are recurring droughts, overgrazing, soil erosion, deforestation and desertification.

Nigeria

Western Africa, bordering the Gulf of Guinea, between Benin and Cameroon; Climate is equatorial in the south, hot and humid in the centre and arid in the north; Southern lowlands merge into central hills and plateaus, high mountains in southeast and plains in the north; Arable land: 33%; Main soil types are Acrisols, Alisols, Arenosols, Fluvisols, Lixisols and Plinthosols; Key issues are periodic droughts, flooding, soil degradation (including contamination from oil spills), deforestation, desertification and a loss of arable soils due to rapid urbanisation.

Rwanda

Central Africa, east of Democratic Republic of the Congo, landlocked; Climate is temperate with two rainy seasons (February to April, November to January). Mountains can be mild but frost and snow possible; Terrain is mostly grassy uplands and hills; relief is mountainous (> 4 500 m) with altitude declining from west to east; Arable land: 46%; Main soil types are Acrisols, Cambisols, Ferralsols, Gleysols and Nitisols; Key issues are soil erosion from overgrazing and other poor farming practices, desertification, industrial pollution and fertiliser runoff.

São Tomé and Príncipe

Central Africa, islands in the Gulf of Guinea, straddling the Equator, west of Gabon – smallest country in Africa; Climate is tropical, hot and humid with one rainy season; Terrain is mountainous, mostly extinct volcanoes; Arable land: 8%; Main soil types are Andosols, Leptosols and Nitisols; Key issues are deforestation, soil erosion and nutrient depletion.

Senegal

Western Africa, bordering the North Atlantic, between Guinea-Bissau and Mauritania; Climate is typically tropical (hot and humid) with a rainy season that is accompanied by strong southeast winds and a dry season (December to April) dominated by the hot, dry, harmattan wind; Terrain is generally low, rolling plains rising to foothills in southeast; Arable land: 13%; Main soil types are Arenosols, Fluvisols, Lixisols, Solonchaaks and Vertisols; Key issues are seasonal flooding (especially in the lowlands), periodic droughts, deforestation, overgrazing, soil erosion and desertification.

Seychelles

Archipelago in the Indian Ocean, northeast of Madagascar; Climate is tropical maritime with humid, cooler season during the southeast monsoon (late May to September) and warmer season during the northwest monsoon (March to May); The Mahe Group is granitic with rocky hills surrounded by a narrow coastal strip. The western islands are flat, low-lying and made of coral; Arable land: 2%; Main soil types are Calcisols, Cambisols and Ferralsols; Key issues are occasional short droughts and sea level rise.

Sierra Leone

Western Africa, bordering the North Atlantic, between Guinea and Liberia; Climate is tropical (hot and humid) with summer rainy season (May to December) and winter dry season (December to April). Nearly 5 000 mm of rain falls annually on the coast to make it one of Africa's wettest region; Terrain is a coastal belt of mangrove swamps, wooded hill country, an upland plateau and mountains in the east; Arable land: 8%; Main soil types are Acrisols, Ferralsols, Fluvisols, Leptosols, Nitisols and Plinthosols; Key issues are dry, sand-laden harmattan winds blowing from the Sahara, soils under pressure from rapid population growth leading to nutrient depletion, overgrazing and deforestation.

Somalia

Eastern Africa, bordering the Red Sea (Gulf of Aden) and the Indian Ocean, east of Ethiopia; Climate is arid (principally desert). During the northeast monsoon (December to February), moderate temperatures in the north and hot in south. During the southwest monsoon (May to October), torrid in the north and hot in the south. Between monsoons the country has hot and humid periods with irregular rainfall; Terrain is mostly a flat to undulating plateau rising to hills in the north; Arable land: 2%; Main soil types are Calcisols, Gypsisols, Leptosols, Regosols, Solonchaks and Vertisols; Key issues are recurring droughts, frequent dust storms over eastern plains in the summer, floods during the rainy season, food insecurity. Deforestation, overgrazing and soil erosion contribute to desertification.

South Africa

Southern Africa, at the southern tip of the continent; Climate is mostly semi-arid with a subtropical Mediterranean climate along the east coast. Days are generally sunny with cool nights. Terrain is a vast interior plateau rimmed by rugged hills and a narrow coastal plain; Arable land: 12%; Main soil types are Arenosols, Calcisols, Cambisols, Leptosols, Luvisols and Planosols - Duriols important locally; Key issues are prolonged droughts, low rainfall in parts, soil contamination (including acidification from industrial emissions), soil erosion and desertification.

South Sudan

East-Central Africa, south of Sudan, north of Uganda and Kenya, west of Ethiopia; Climate is hot with seasonal rainfall influenced by the annual shift of the Inter-Tropical Convergence Zone. Rainfall is heaviest in the upland areas of the south and diminishes to the north; Terrain gradually rises from plains in the north and centre to highlands along the border with Uganda and Kenya. The White Nile is the major geographic feature of the country supporting agriculture and extensive wild animal populations. The Sudd, a large swampy area fed by the waters of the White Nile, covers more than 100 000 km^2 (more that 15% of the country) and is one of the world's largest wetlands; Arable land: estimated that only 4% of arable land is cultivated; Main soil types are Arenosols, Leptosols, Lixisols, Plinthosols and Vertisols; Key issues are dust storms and periodic persistent droughts, soil erosion and desertification.

Sudan

North-eastern Africa, bordering the Red Sea, between Egypt and Eritrea; Climate is hot and dry - rainy season varies by region; Terrain is generally a flat, featureless plain with desert dominating the north; Arable land: around 6%; Main soil types are Arenosols, Calcisols, Ferralsols, Fluvisols, Leptosols and Vertisols; Key issues are dust storms and periodic persistent droughts, soil erosion and desertification.

Swaziland

Southern Africa, between Mozambique and South Africa – almost surrounded by South Africa; Climate varies from tropical to near temperate; Terrain is mostly mountains and hills with some moderately sloping plains; Arable land: 10%; Main soil types are Acrisols, Leptosols, Ferralsols and Nitisols; Key issues are drought, overgrazing and soil erosion.

Tanzania

Eastern Africa, bordering the Indian Ocean, between Kenya and Mozambique; Climate varies from warm tropical along the coast to cool tropical in the highlands; Terrain is basically coastal plains, a central plateau and highlands in the north and south. Kilimanjaro is Africa's highest mountain (5 895 m) and one of only three mountains on the continent that has glaciers. Bordered by three of the largest lakes on the continent - Lake Victoria (the world's second-largest freshwater lake), Lake Tanganyika (the world's second deepest) and Lake Nyasa (Lake Malawi); Arable land: 4%; Main soil types are Acrisols, Alisols, Ferralsols, Lixisols, Nitisols, Plinthosols and Vertisols; Key issues are flooding on the central plateau during the rainy season, droughts (affecting marginal agriculture), extensive soil degradation, deforestation and desertification.

Togo

Western Africa, bordering the Gulf of Guinea, between Benin and Ghana; Climate is tropical, hot and humid in the south, semi-arid in the north; Terrain is gently rolling savannah in the north, central hills, a southern plateau and a low coastal plain with extensive lagoons and marshes; Arable land: 44%; Main soil types are Acrisols, Alisols, Fluvisols, Lixisols, Plinthosols and Vertisols; Key issues are hot, dry harmattan wind deposits fine sediments, periodic droughts and deforestation, mostly associated with slash-and-burn agriculture and the use of wood for fuel.

Tunisia

Northern Africa, bordering the Mediterranean Sea, between Algeria and Libya; Climate is temperate in the north with mild, rainy winters and hot, dry summers - desert in south; Mountains in north with hot, dry central plain. The south of the country is generally flat and merges into the Sahara, large salt depressions; Arable land: 17%; Main soil types are Arenosols, Calcisols, Cambisols, Fluvisols, Gypsisols, Leptosols, Luvisols and Solonchaks; Key issues are overgrazing, salinisation, urbanisation, soil erosion and desertification.

Uganda

Eastern Africa, west of Kenya, east of the Democratic Republic of the Congo, landlocked; Climate is tropical, generally rainy with two dry seasons, semi-arid in the northeast; Terrain is mostly plateau with rim of mountains. Ruwenzori in the east reach over 5 000 m and have permanent snow, ice and glaciers; Arable land: 22%; Main soil types are Acrisols, Ferralsols, Fluvisols, Gleysols, Nitisols and Plinthosols; Key issues are draining of wetlands for agricultural use, deforestation, overgrazing and soil erosion.

Western Sahara

Northern Africa, bordering the North Atlantic, between Mauritania and Morocco; Climate is hot and dry desert, rain is rare, cold offshore air currents produce fog and heavy dew; Terrain is mostly low, flat desert with large areas of rocky or sandy surfaces rising to small mountains in the south and northeast. Lowest point is -55 m below sea level; Arable land: negligible; Main soil types are Arenosols, Calcisols, Leptosols, Regosols and Solonchaks; Key issues are wind erosion, sparse water and a lack of arable land.

Zambia

Southern Africa, east of Angola, south of the Democratic Republic of the Congo, landlocked; Climate is tropical, modified by altitude, with a distinct; rainy season (October to April); Terrain is mostly high plateau with some hills and mountains. Lake Kariba, on the Zambia-Zimbabwe, border is the world's largest reservoir by volume (180 km^3); Arable land: 7%; Main soil types are Acrisols, Arenosols, Ferralsols, Gleysols, Leptosols, Lixisols and Nitisols - some Podzols; Key issues are periodic droughts; tropical storms (November to April) giving rise to flash floods and erosion, soil contamination from mineral extraction and industrial emissions, deforestation and desertification.

Zimbabwe

Southern Africa, between South Africa and Zambia, landlocked; Climate is tropical; moderated by altitude and a rainy season from November to March; Terrain is mostly high plateau with higher central plateau (high veld) and mountains in the east; Arable land: 8%; Main soil types are Arenosols, Leptosols, Lixisols, and Luvisols; Key issues are recurring droughts, deforestation, soil erosion and general land degradation. Mining practices have led to toxic waste and heavy metal pollution of soils.

Island territories

Ascension, Saint Helena and Tristan da Cunha

Islands in the South Atlantic, about midway between South America and Africa - British Overseas Territories; Saint Helena has a tropical marine climate tempered by trade winds, Ascension Island is similar but a little drier while Tristan da Cunha is cooler with a temperate marine climate; The islands are the result of volcanic activity associated with the Mid-Atlantic Ridge which gives rise to a rugged, mountainous landscape; Arable land: 13%; Main soil types on both locations are Andosols, Cambisols and Leptosols; Volcanic activity is an important issue.

Azores and Maderia

The Azores are a group of islands (nine major ones) in the North Atlantic, some 1 600 km west of mainland Portugal while Maderia lies 500 km from the coast of Africa, west of the Canary Islands - both are autonomous regions of Portugal; Climate on the Azores is subtropical with high humidity while Madeira has a Mediterranean climate but issues such as exposure, humidity and elevation give rise to distinct microclimates; The islands are the result of volcanic activity which gives rise to a rugged, mountainous landscape; Arable land: 5%; Main soil types are Andosols, Cambisols and Leptosols; Volcanic activity and erosion are important issues.

Canary Islands

Western Africa, group of islands in the North Atlantic, some 100 km west of Morocco - an autonomous region of Spain; Climate is warm, subtropical showing little seasonal variation. Elevation affects temperature; The islands are the result of volcanic activity which gives rise to a rugged, mountainous landscape; Arable land: 26%; Main soil types are Andosols, Cambisols and Leptosols; Forest fires, landslides and erosion are important issues.

Malta and the Pelagie Islands

Northern Africa, small islands in the central Mediterranean off the coasts of Libya and Tunisia. Malta is an independent state of the European Union while the Pelagie are part of Sicily (Italy); Climate is Mediterranean with rainy winters and hot, dry summers; Terrain is rocky, mostly low-lying plateaus; Arable land (Malta): 30%; Main soil types are Calcisols, Cambisols, Leptosols and Andosols (Linosa); Key issues are droughts, desertification, low soil organic matter.

Global change

Global change refers to planetary-scale changes in the state and dynamics of the Earth's key systems: land, oceans, atmosphere, poles, living matter (including humans), natural cycles and deep Earth processes. These single elements are dependent on, and influence, one another. The Earth system now includes human society, so global change can also refer to large-scale changes in society. Human or social aspects of global change include the economy, resource use, energy development and consumption, transport, communication, land use and land cover, urbanisation, globalisation, food webs, biological diversity, pollution and health.

In the past, the main drivers of global change have been factors such as solar or orbital variations, plate tectonics, volcanism, proliferation and abatement of life and meteorite impacts. However, there is increasing evidence that the main driver in recent years is the seemingly insatiable human demand for energy, food, goods and services. Coupled to these demands is the impact of waste products on the planet as a whole. Many scientists believe that over the last century, human activities has caused climate change, widespread species extinctions, the collapse of fish-stocks, desertification, ocean acidification, ozone depletion and pollution.

Organisations such as the European Union and the United Nations are calling for a more sustainable approach to how we manage the resources of the planet. Several international environmental conventions now exist under the UN to address these challenges. They include the Framework Convention on Climate Change (UNFCCC), the Montreal Protocol, the Convention to Combat Desertification (UNCCD) and Convention on Biological Diversity (UNCBD). As you may have gathered from this atlas, the rational use and protection of soil resources is at the heart of these actions. [93, 94, 94a]

Above: A fruit and vegetable market stall in Morocco. A healthy, productive soil is vital to human health. (SH)

Below: A small rural village in Swaziland. The photograph shows that the soil is used as a construction material (walls of the buildings), to provide fibre (roofs), food production (field to the right of the path), fodder (pasture to the left of the path) and fuel for shelter, cooking and heating (trees). (CG)

Soil awareness raising and education

Soil awareness

"Upon this handful of soil our survival depends. Husband it and it will grow our food, our fuel, and our shelter and surround us with beauty. Abuse it and the soil will collapse and die, taking humanity with it"

From Vedas Sanskrit Scripture – 1500 BC

The need to raise awareness and understanding of the importance of soil and soil functions, both in urban and rural environments, is being recognised increasingly as a critical step in the protection and sustainable use of soils both in Africa and globally. This atlas shows that a number of threats to soil quality are recognised (e.g. erosion, loss of organic matter, landslides, contamination, compaction, desertification, salinisation and soil sealing) which have an impact on the functioning of soils across Africa.

However, soil protection is not explicitly included in the legislation of most African countries. Therefore, increasing everybody's knowledge about soil through education and research is the first logical step to allow society as a whole to understand and appreciate soil and its importance.

What does soil awareness mean?

Soil awareness means developing a responsible behaviour towards soils and soil management, based on knowledge and attitude. The more we can learn about the role that soil plays in sustaining the environment, the more we understand how important it is and, hopefully, the more likely we are to look after it.

Who needs to know about soil?

It is important that we teach the importance of soil to society at large. From young children, school teachers, farmers, gardeners and industrialists to planners and politicians.

Children, of all ages, love playing with soil and have the capacity to learn so much, with simple "hands-on" activities from comparing textures to making mud pies, building wormeries and looking at what lives in soil under the microscope. A child's perspective on what we think about when we talk about soil functions and the role of soil organisms often reflects a clearer appreciation than adults.

Drawings made by children show how they perceive soil. Perhaps surprisingly, how they often describe soil as an essential part of the entire ecosystem. Such sketches or paintings, especially by primary school children, often convey complex messages such as the food chain or the importance of earthworms in increasing the pore network underground, which in turn aids infiltration of rain water.

This is a lesson that soil scientists constantly strive to communicate, but often over-complicate. The ecosystem view is, however, apparently inherent to most children who also seem to be fascinated by life in the soil, be it at primary, secondary or even university level.

Other actors who need to be included in education and awareness raising are:

University students

The knowledge of soil in general, and soil biology and ecology in particular, is often neglected, even in faculties having a direct connection with the study of terrestrial ecosystems. It is clear that the study of soil biota should be improved at university level, not only in subjects such as agricultural sciences, forestry and environmental sciences, but also in engineering, architecture and land use planning, because they also deal with the management of our planet.

Environmental scientists

Environmental science should be characterised by a very holistic approach. This can be achieved by having an inter-disciplinary team consisting of people that are specialised in different subject. However, this optimal situation is threatened by the fact that some disciplines become neglected.

Policy makers

The decisions of policy makers affect our everyday life. Often the temporal horizon in politics is very limited and more related to political elections than to real-world processes. Increasing awareness of the importance and value of soil in decision-making processes could bring enormous benefits.

Farmers and land managers

Farmers generally have a good knowledge about and feeling for soil because it represents the most important factor of their activities. However, the functioning of the living soil system is not so obvious and some farming practices may have to be limited or curtailed. A possible further problem is that farmers are being increasingly asked to react to a short-term market-driven pressures rather than a long-term perspective. This is driven by the switch from traditional systems to more industrial approaches.

Public

Ultimately, the most important goal must be to raise soil awareness among the general public. In a democratic system, this is the only way to have a bottom-up change in lifestyle, aimed towards a more sustainable use of our planet.

Examples of public engagement with soil (**clockwise from above**:) introducing soil as a habitiat at the Conference of the Parties to the UN Convention to Combat Desertification. (PL); young children learning through fun at the JRC Open Day soil exhibit. (EA); hands-on training in Tanzania of how to record a soil profile. (VL); inspection of a Nitisol profile in Zimbabwe. (EVR)

Right: a young child's drawing captures soil horizons, soil biology and the role of soil in food production. (JRC)

Where can you learn about soil?

Often the best place to teach people about soils is to actually visit a field, woodland or a garden. In these environments, students can investigate for themselves soil characteristics and the role it plays in keeping our environment alive.

Simply digging a small hole, lifting stones to see what lies underneath, sifting through plant litter or just setting a few pitfall traps made from plastic containers will quickly bring you in to contact with soil biota.

The use of magnifying lenses or microscopes to show the variety of soil organisms found in a few grammes of soil is such a simple lesson and is guaranteed to leave a long lasting impression.

A huge amount of educational material is increasingly being made available for both students and teachers. This includes computer programmes, lesson plans, supporting materials and activities for both the classroom and outdoors.

The great thing about the teaching of soil-related matters is that it is applicable across all ages from young children, to school leavers, university students and mature gardeners and farmers.

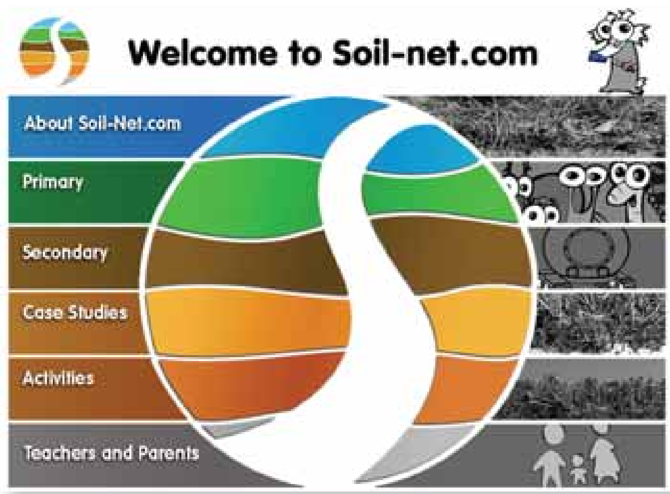
Soil at school

Most indigenous African cultures are inherently aware of the relationship between soil quality and food production. However, with an increasingly urban population and the prevalence of inappropriate land management practices, it is important to re-emphasise the role of soil in human existence at an early age.

Educating children to conserve and use the soil sustainably to grow healthy plants is the first step towards food security and the reduction of poverty. A minimal improvement in soil quality, coupled with a little water, can support the production of fresh and healthy food. The development of school gardens can not only teach children about practical issues such as horticulture, composting, water management and food production, but also about issues concerning land management, economics, poetry and mathematics. In addition, a communal garden project gives a sense of collective responsibility as pupils need to collaborate to make the garden grow. In addition, the children feel a high sense of achievement when they bring their produce home as they feel that they are also contributing to the well-being of their family.

In addition to the practical skills learnt in garden projects, soil can also be used as the basis of many aspects of the curriculum. Younger children can be taught to recognise the properties of different types of soil that exist in their community while soil colour, a simple but effective assessment tool, can be easily introduced through art classes.

In secondary schools, the reactions taking place in soil are real, everyday examples of the theories being taught in chemistry lessons. The movement of water and pressure of machines on soil structure are just two topics that easily fit into any physics course. However, the easiest place to include is in the biology class. By its definition, soil is a living medium and soil biodiversity is the key driver of most soil processes. In this case, the study of soil fauna easily lends itself to the classroom. The role of earthworms, soil-dwelling mammals and the food chain are concepts that are easy to communicate to younger children. The role of soil micro-organisms in nutrient cycling or greenhouse gas fluxes and the symbiotic relationships between plants and fungi are well within the understanding of secondary school pupils.



Increased access to internet learning resources will allow increased access to online educational resources such as Soil-Net. (SH)

Soil education resources

In order to educate children on the role and importance of soil, teachers themselves must be aware of the issues and have access to sufficient classroom resources.

Ensuring that teachers have a sufficient knowledge base to educate children must be a long-term goal that reflects both an increasing desire to see soil included as a topic in national curricula and a realisation that soil protection is beneficial to the well-being of a country.

Higher education soil science establishments and national soil science societies can, and probably even should, play an active role in this process. Unfortunately, in most African countries, the lack of national soil survey institutes means a lack of outreach and public engagement programmes. In addition, the soil science community traditionally has not engaged with the general public and the scholastic community. Fortunately, there are a number of sites on the internet that make such material freely available. These include:

- **Soil-Net Cranfield University**
  http://www.soil-net.com
- **NASA Soil Science Education**
  http://soil.gsfc.nasa.gov/index.php?section=7
- **USDA Natural Resource Conservation Service**
  http://soils.usda.gov/education
- **European Commission, JRC**
  http://eusoils.jrc.ec.europa.eu/Awareness/
- **Soil education camp**
  http://kanchanapisek.or.th/kp14/project_dev/project_area/Ratburi/pdf/ee4_Soil.pdf
- **British Soil Science Society**
  http://www.soils.org.uk/pages/education
- **Dirt: The movie**
  http://www.thedirtmovie.org/
- **French Soil Association**
  http://afes.fr/ressources.php

A Thousand Gardens in Africa

A number of non-governmental organisations (NGOs) and charities are actively developing soil awareness and education schemes in Africa. Of special note is the ambitious initiative of the Slow Food Foundation for Biodiversity which has embarked on an project to create a thousand food gardens in schools, villages and on the outskirts of cities in 25 African countries. The overall aim is to provide a community with a vital source of healthy food and an example of local, sustainable agriculture for farmers and householders to learn from.

http://www.slowfoodfoundation.com/

Raising awareness: soil science's greatest challenge?

It could be argued, rather unfairly in the eyes of many, that soil science lacks a certain 'wow' factor! Despite the vast body of scientific knowledge, the role and importance of soil is often not fully understood, appreciated nor valued by society at large. Nor, in general, by policy makers or other scientific domains. Conversely, one of the reasons for this situation is the limited awareness or understanding of the role that soil plays!

An increasingly urban society (not only in Africa) has become detached from subject matter. Food appears on the shelves of supermarkets but the processes behind its production are shrouded from the public. As alluded to on this page, there is almost no soil component in the education of most people. Arguably, the only group who still have a direct contact with soil are the farming community. However, as a result of external pressures, poverty or lack of education, many have lost the skills needed to maintain their soils in a sustainable manner.

In many countries, soil management or protection is simply not accepted as a priority. This is due to conflicting policy drivers (reflecting the cross-cutting nature of soil) combined with the perception that soil is too complex a media to consider legislating.

A further consideration is that many soil scientists are driven by science. They are focused on narrow fields of competence with an obligation to their employers (or funders) to publish in scientific journals. While such an approach is critical for the development of the knowledge base that underpins the discipline, there is a considerable challenge in transmitting this information to the wider public. In simple terms, most policy makers and politicians do not read scientific journals! In addition, most soil scientists have very limited interaction with public education activities.

In essence, there is a need for the soil science community, possibly driven by national soil science societies, to increase proactively its levels of public interaction. Initiatives to raise awareness of the importance of soil for human and ecosystem survival probably bring the soil science community in contact with audiences beyond the normal scope of scientific communication activities. However, more soil scientists should realise that public engagement can be fun, rewarding and beneficial and, as most soil science is publicly funded, such public interaction should be encouraged as a rightful return to society.

A Naked Mole Rat (*Heterocephalus glaber*) is a rodent that is native to the dry savannahs of East Africa. They spend virtually their entire life underground, eating roots and tubers. They can travel backwards as quickly as they can move forwards and their large teeth are used to help them dig. They prefer areas with sandy or loamy soil. (RK)

Children taking care of their school garden in The Gambia. Education on the sustainable use of soil is the major step in combating malnutrition and reducing poverty across rural and urban Africa. (HC)

Conclusions and future challenges

The soils of Africa are diverse. They range from bare and dry sandy dunes in the Namib Desert of Kalahari to fertile, life-sustaining soils on the slopes of the volcanoes in the Rift Valley. The economies of many African countries are highly dependent on their soil base, while rural populations often depend on the fertility of the soil for their survival (top left: rice growing in flooded bunds on a Gleyic Fluvisol in Lindi, Tanzania. (JD); false banana (*Ensete*) plants on Nitisols close to Jimma, Ethiopia make a lush scene. False banana, commonly known as the Ethiopian banana, is an economically important foodcrop in Ethiopia while a good quality fibre is obtained from the leaves. (EVR)

While soil degradation is a major concern across Africa, especially in relation to human health, food security, rural poverty and loss of biodiversity, careful management and sustainable use of soils will help combat these issues. In fact, in many parts of Africa, land restoration project are making significant progress. The lower pair of images show the same location in Tigray, Ethiopia. The image on the left (NM) was taken in 1974 while the one on the right in 2006 (JN). While the population in the area has more than doubled since 1974, natural regeneration and a tree planting scheme, together with the adoption of soil and water conservation practices, means that environmental restoration in enclosures is a well-documented fact in Ethiopia. In reality, there are now more trees than people in Tigray [96].

Conclusions

Soil is defined as the top layer of the Earth's crust. It is a natural substance composed of weathered rock particles (minerals), organic matter, water and air. A typical sample of mineral soil comprises 45% minerals, 25% water, 25% air and 5% organic matter – however, these proportions can vary.

Soil is a habitat and gene pool, it serves as a platform for human activities, landscape and heritage, and acts as a provider of raw materials. A healthy, fertile soil is at the heart of food security. Its functions are worthy of protection because of their socio-economic as well as environmental importance.

Soil-forming processes tend to be slow and occur over long periods — typical rates of soil formation under permanent grasslands in temperate climates are in the order of only 1–2 cm per 100 years.

Soil that is lost due to degradation processes (e.g. erosion, pollution) would need hundreds or thousands of years to recover naturally. Compared to the lifespan of human beings, soil loss is not recoverable which means that soil must be regarded as a non-renewable resource.

The soil resources of Africa are diverse. However, many soils are inherently fragile, being low in nutrients and organic matter. A lack of water is a major constraint to their use in agriculture.

Despite technological advances, soil will always be necessary for humans to grow most of their food, fodder, fuel and fibre. More than 95% of the food consumed in Africa comes from the land as does fuel wood for cooking and heating.

The food requirements of the population of Africa, projected to reach two billion in 2050, are currently estimated to be 0.7 billion tonnes per year. On the one hand, this represents a profound challenge for the African agricultural community. However, it is also a great opportunity for the development of sustainable soil management practices to meet the increasing food demand.

Through a sound understanding of the natural soil processes and the interactions of the soil with water, air, biota and humans, it should be possible to optimise the productivity of the soil, while ensuring ecological and environmental conservation.

The unsustainable use and management of land is leading to increased soil degradation and the loss of a key resource that is fundamental to life on the continent of Africa. Notable issues are a loss of nutrients and soil organic matter, contamination, erosion, landslides, salinisation, biodiversity decline, compaction and sealing through urbanisation and infrastructure development.

The degradation of land resources has a negative impact on rural and urban livelihoods. For instance, over production and an absence of nutrient management has led to exhausted or infertile soils. This state, coupled with increasing aridity gives rise to desertification which is known to have increased the level of poverty in rural areas. In turn this leads to population migration in to cities and increasing rates of poverty.

Planners, decision makers and users of the land need to be more aware that agricultural production depends on the productivity of soils and the sustenance of production depends on proper utilisation of the soil resources. This is because land is not an infinite resource. Indeed, interactive competition for the same piece of land for different uses (e.g. roads, buildings, forests and agriculture) has, for the past years, overtaxed the resilience of natural processes, thereby causing severe land degradation and a decline in soil productivity. Therefore, strategies for intensification of agricultural production should aim to achieve high yields per unit area while at the same time improving soil health and conserving water resources and environmental vitality. This can be achieved when land users are informed of the potential and management requirements of a given area of land identified for a specific purpose.

However, the prevention of soil degradation is also limited by the scarcity of data (see adjacent page). African countries should consider the development of a harmonised approach to soil monitoring and data collection programmes.

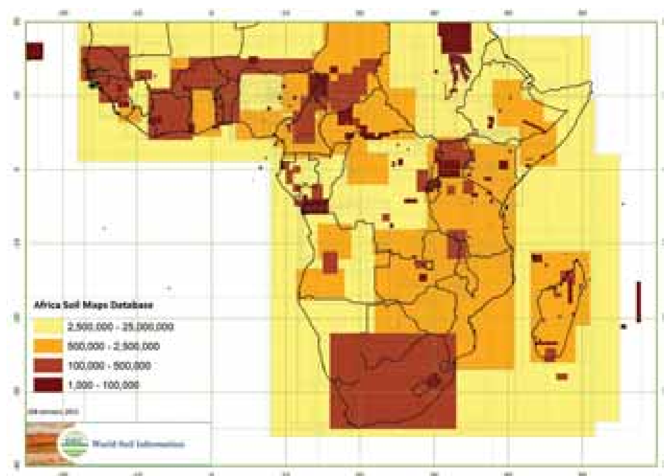
Climate change may worsen soil degradation and cause further desertification. More frequent and more severe droughts will cause soil water retention mechanisms to collapse, leading to erosion and the onset of desertification.

Additional support is needed to develop research projects, particularly into the understanding of the economic, social and environmental benefits of soil functions and the impact of degradation processes over time.

Finally, a key focus must be the development of initiatives to raise awareness in society as a whole of the value and importance of soil. Education is an important element of soil protection. We count on all stakeholders and particularly succesive generations to take care of soils as key resource for Africa's future development.

Last word

There is a growing realisation that knowledge of soil, a fragile but vital resource that is not easily renewed on a human scale, is vitally important for our understanding of the environment. In Africa, the lack of easily accessible reference books means that the discovery of soil, and the role that it plays in our lives, is limited to universities or narrow scientific domains. This atlas aims to provide an understandable introduction that will help Africans from all walks of life to discover and use the soils of Africa sustainably. To reach an even wider audience, it is foreseen that this edition will be translated into French and Arabic. Finally, the Soil Atlas of Africa would certainly not have been produced without the scientific heritage that was left by the many European soil scientists who travelled and worked in Africa. The Editors take this opportunity to pay tribute to these pioneers.



Along with water, soil is one of the most important resources for supporting life on the planet yet it is greatly undervalued. Significant areas of soil are being lost to non-agricultural uses or to degradation as a result of soil erosion by water or wind, salinisation, waterlogging, depletion of plant nutrients, deterioration of soil structure, desertification and pollution. Since humanity's existence depends on their continued productivity, these developments are alarming in the light of increasing needs for food, fibre and firewood. In this context, the use of soil resources should not cause their degradation or destruction. Governments have a major responsibility for the development of land-use programmes that include measures which ensure the optimum exploitation of the land while ensuring its long-term maintenance and avoiding losses of soil. Soil degradation not only affects agriculture and forestry by diminishing yields but also other sectors of the economy through secondary pressures such as population migration, civil unrest, urban flooding and the silting up of dams and ports. New data collection and monitoring, together with education and awareness raising of the importance and value of soil are critical considerations. **Clockwise from lower right**: there is a lack of current, consistent, detailed and comparable data on soil resources and trends across Africa. Large parts of the continent lack even medium scale soil map coverage. National soil survey programmes and monitoring systems are virtually non-existent in most countries and the data that exist are sometimes 50-60 years old, often with limited applicability to contemporary needs (ISRIC); Tunisian farmers adding vital organic matter to their soil (TG); a surveyor digging a soil profile in a Lixisol in the Dodoma Region of Central Tanzania in order to collect new data for analysis (VL); scientists from the East Africa Soil Science Society explaining soil management methods to farmers (EM).

Improved knowledge base

To facilitate policy development and decision-making relating to the most appropriate use of terrestrial resources, relevant and up-to-date information on the state of soils is critical. This information is traditionally obtained through soil surveys and related land resource inventories. In combination with socio-economic data, soil data can be analysed and interpreted in the process of land evaluation to indicate the suitability of different tracts of land for various uses. Such information can also be used as a baseline for monitoring changes in the state of natural resources under different usage. In this context, the development of a soil monitoring programme is essential. At present, there is a marked lack of current, consistent and comparable data on soil resources and trends across Africa. National soil survey programmes and monitoring systems are virtually non-existent in most countries. The data that exist are sometimes 50-60 years old and often have limited applicability to contemporary needs. There is little coherence between countries which makes the quantitative evaluation of changes in soil state and functions almost impossible. The lack of data also hampers efforts to develop indicators to measure the situation, especially in relation to the main threats to soil that have been described in this publication.

Initiatives such as the African Monitoring of the Environment for Sustainable Development (AMESD) Programme could form the basis for focused collection of soil data. The innovative initiative of the African Soil Information Service to predict key soil parameters across sub-Saharan Africa will be a tremendous asset and could be incorporated within the AMESD framework. However, it should not be a total replacement for field data collection. The maintenance and development of soil education components at all levels should also be a priority. Without a trained scientific base, the collection of relevant soil information will be impossible.

Policy approaches

In recent years, there has been an increasing appreciation of the value of soil to society and a realisation that soil needs at least the same level of attention and protection as air and water. In fact, many social crises in Africa are triggered to a large extent by inadequate soil and water management policies and practices.

In 1982, the FAO adopted a World Soil Charter detailing some basic principles and guidelines for sustainable soil management and soil protection to be followed by governments, international organisations and users of the land. The Charter calls for a commitment to manage soil resources for long-term benefit rather than for short-term expediency. Special attention is drawn to the need for land-use policies that create incentives for people to participate in soil conservation work, taking into account both the technical and socio-economic elements of effective land use.

However, in many parts of Africa, the principles of the Charter have not or are not being applied. As a response, the Global Soil Partnership of the FAO gives a strong signal that politicians and policy makers should take note of the value of soil and how it is being utilised across their territories. Awareness raising must be coupled with a supportive policy environment and technical solutions that lead to the effective protection and management of soils.

In parallel, long term and large-scale measures are needed in order to build greater resilience to soil degradation and reduce human vulnerability to disaster events. Key to this goal is the enhancement of capability and capacity for soil survey and monitoring, with a particular focus on assessments of soil productivity, soil carbon and soil biodiversity in light of soil and water conservation.

A common approach to the soils of Africa?

The final statement of the Rio+20 Conference in 2012, world leaders agreed to recognise the need for urgent action to reverse land degradation and to strive to achieve a 'land-degradation neutral world' in the context of sustainable development. The text notes the importance of maintaining and protecting soil resources [94].

At present, there is no common pan-African framework to encourage the sustainable use of soil and preserve its essential functions. National authorities, under the leadership of the African Union Commission or regionally with partners in respective African Economic Zones, could initiate:

- **an assessment of the state of soils and associated threats** to identify areas at risk of erosion, decline in nutrients and organic matter, salinisation, acidification, compaction or landslides. This could be combined with an inventory of contaminated sites;
- **preventative measures** to assess the impacts of current policies and land use practices on soil quality in areas such as agriculture, waste, urban development or mining, and to ensure the sustainable use of soil and its functions;
- **action programmes** to deal with the main issues of local concern, along with remediation strategies for degraded and contaminated land;
- **requirements for the collection** of harmonised soil information.

At the heart of such a framework should be support to facilitate networking of soil scientists and land use experts from all parts of Africa. Such a move would help to improve information exchange and develop a more comprehensive knowledge base to underpin sustainable soil use policy development and practices.

Ancillary information

Glossary

This page explains some of the more technical words and phrases used in the atlas. Readers can avail themselves of additional explanations from the many comprehensive glossaries that can be found on the Internet. For example:

Technical definitions of soil terms from the ASSS:

https://www.soils.org/publications/soils-glossary

Soil terms explained for children/general public:

http://www.soil-net.com

Definitions

acid: a substance which reacts with a **base**, denoted by **pH** < 7. Substances having the property of an acid are said to be acidic.

active layer: part of ground that is subject to annual **thawing** and **freezing** in areas underlain by **permafrost**.

adsorption: process by which atoms, molecules or ions are retained on the surfaces of solids by chemical or physical binding.

aeolian: relating to wind, sediments comprising wind-blown material (usually sands).

aggregate: soil particles bound together by water, organic films or biological activity. Classified by size, shape (e.g. platy) and grade (e.g. strong).

agriculture: the production of animals and plants for food, fibre and fuel, also called farming.

agriculture, conservation: farming system that aims to minimise loss of soil and water and increase **organic matter** levels, involves **zero- or minimal tillage** while leaving **crop** residues on the surface to protect the soil.

agriculture, subsistence: farming system where the focus is on producing enough food to maintain a specific group of people. Shifting cultivation and nomadic pastures are the main examples.

alkalines: any of various bases, the hydroxides of the alkali metals and of ammonium, that neutralize acids to form salts.

alluvium: deposit made by a river or running water, often very productive agricultural soil.

anaerobic: conditions where very little oxygen is present (e.g. the waterlogged soil in a bog).

anion: particle with a negative charge. See also **ion, cation**.

anthropogenic: generated by humans.

arable land: land that is cultivated by **ploughing**.

base: a substance that can accept hydrogen ions, opposite to acid.

biofuel: liquid fuels produced from **biomass** (e.g. maize).

biomass: the total amount of living plants above and below ground in an area at a given time.

biome: areas of the Earth's surface with distinct climate-flora/fauna relationships (**e.g. tropical rainforest**).

bog: wetland without any significant inflows or outflows.

buffering capacity: ability of the soil to reduce high alkalinity or acidity levels (e.g. calcareous soils can neutralise acids).

bulk density: dry mass of soil per unit volume (kg m^{-3}).

carbon: non-metallic chemical element with symbol C and atomic number 6, essential building block of all living matter. Occurs in variety of forms (e.g. coal, diamond). Constituent of fossil fuel and **carbon dioxide**.

carbon cycle: transformation of carbon dioxide to organic forms by photosynthesis, recycled through the biosphere (with partial incorporation into sediments) and ultimately returned to its original state through respiration or combustion.

carbon dioxide: naturally occurring chemical compound composed of two oxygen atoms bonded to a single carbon atom (CO_2). A gas at standard conditions. In photosynthesis, plants absorb carbon dioxide to produce carbohydrate energy. Also produced by combustion of hydrocarbons (e.g. petrol), the fermentation of liquids and the breathing of mammals. A **greenhouse gas**.

carbon sink: a medium that absorbs or takes up released carbon from another part of the **carbon** cycle, nominally the atmosphere, terrestrial biosphere (including soil), oceans and geological sediments (including fossil fuels).

carbon sequestration: the fixation of atmospheric carbon dioxide in a carbon sink through biological or physical processes, for example, as organic carbon in soils.

cation: particle with positive charge.

cation exchange: interchange between a cation in solution and another cation in the boundary layer between the solution and the surface of negatively charged material (e.g. clay or organic matter). Main process behind uptake of soil nutrients by plants.

cation exchange capacity: the ability of soil to hold **nutrients** for plant use, also referred to as CEC.

clay: soil particle smaller than 0.002 mm or 2 μm.

clay minerals: clay-sized silicates having a large interlayer space that can hold significant amounts of water and other substances (e.g. montmorillonite, smectite, kaolinite).

climate: commonly defined as the weather averaged over a long period, classically 30 years.

coating: thin layer of a substance completely or partly covering a surface; soil coatings can comprise clay, calcite, gypsum, iron, organic material, salt, etc.

colluvium: unconsolidated, unsorted material associated with transportation and/or deposition by mass movement and local, unconcentrated runoff on slopes and/or at the base of slopes.

coniferous: trees, such as spruces, hemlocks, pines and firs. The leaves of these trees are needle-like and most stay green all year round (evergreen). The larch is a coniferous tree which loses its leaves in autumn. All conifers are softwoods and are able to thrive on acidic soils.

contaminant: an unwanted constituent in a substance, usually degrades the receiving material. Can cause damage or harm (e.g. pesticide in water) but not always (e.g. water in wine). See **pollution**.

crop: plants cultivated for food, fibre or fuel. Often undertaken on a large scale. Major crops include maize, wheat, rice, cassava, potatoes and cotton.

cuirasses: indurated horizons rich in iron and or aluminium compounds (oxides, hydroxides). Often referred to as ferruginous or ferralitic crusts.

deforestation: the removal of trees from forested land.

electrical conductivity: measure of how well a soil conducts an electrical charge, determines salinity.

eluviation: the movement of dissolved or suspended material within soil, generally downwards.

emissions: releases of gases to the atmosphere, can be natural or man-made (e.g. the release of carbon dioxide during fuel combustion or burning of **biomass**).

erosion: the wearing away of land or soil through one or more processes. Wind and water are the main processes affecting soil. Can be triggered by poor land management such as overgrazing or deforestation.

fallow: practice of leaving land either uncropped or with regenerative vegetation during at least one period when a crop would normally be grown, with a view to restoring plant nutrients.

fen: flat and swampy land, usually at low altitude.

fertilisation: application of **fertiliser** in order to improve specific soil properties and increase soil fertility.

fertiliser: any material which is added to the soil to supply plant nutrients. Organic fertilisers are derived on the remains of plants or animal excretion (e.g. decomposed crop residues, manure) while inorganic fertilisers are either mined or chemically synthesised in laboratories. Fertilisers typically provide a range of soil **macronutrients** and **micronutrients**. Main components are nitrogen (N), phosphorus (P) and potassium (K), in varying proportions.

field capacity: soil moisture state after heavy rain when all downward movement of water has ceased.

fluvial: relating to a river or rivers.

freezing: change of phase from water to ice. Occurs at 0°C.

forest: an area with a high density of trees (woodland).

function: a service, role or task that meets specific objectives.

geology: scientific field concerning the study of rocks, also used to denote solid material from which most soil is formed, characterised by the horizon symbol 'R'.

geomorphology: science which studies landforms.

glaciers: large masses of ice that form by the compaction and recrystallisation of snow under freezing conditions; move downslope under their own weight.

grazing: the regular consumption of part of one organism by another organism without killing it (e.g. cattle feeding on grasslands).

gully: channel resulting from the concentrated but intermittent flow of water during and immediately following heavy rain.

greenhouse gas: a gas in the atmosphere which prevents heat (longwave infrared radiation) from being radiated into space. A driver of global climate change.

groundwater: water below the surface of the ground. See also **water table**.

habitat: the native environment in which a given animal or plant naturally lives or grows.

harvest: the process of gathering mature crops which marks the end of the growing cycle for the harvested crop. The removal of **organic matter** through harvesting and subsequent transfer to market is one of the main causes of **nutrient losses** in soil. Heavy loads during harvest cause **soil compaction**. The harvesting of cereal crops is referred to as reaping.

hectare: metric unit of land area defined as 10,000 m^2 (i.e. 100 m by 100 m). Abbreviated to ha.

horizon: layer of soil or soil material approximately parallel to the surface and differing from adjacent genetically related layers in physical, chemical and biological properties or characteristics such as colour, structure, texture, acidity, etc.

humification: process whereby the carbon of organic residues is transformed and converted to **humic** substances through biochemical processes.

humus: organic compounds in soil, exclusive of undecayed plant and animal tissues, their partial decomposition products, and the soil biomass; humus possesses an amorphous structure, low specific weight and high surface area. Humus is important for soil fertility and helps to bind soil particles and aggregates.

hydrogen: chemical element with symbol H and atomic number 1. A colourless, odourless, tasteless, non-toxic, highly combustible gas with the formula H_2 at standard conditions, hydrogen is the most abundant chemical substance in the Universe. Present in the water molecule and in most organic compounds. Hydrogen plays a particularly important role in acid-base chemistry (see cation exchange).

hydraulic conductivity: a quantitative measure of how easily water flows through soil (see **infiltration** and **permeability**).

hydromorphic soils: formed under conditions of poor drainage in marshes, swamps, seepage areas or flats.

ice: water in the solid state.

illuviation: the accumulation in one layer of soil of materials that have been leached out of another layer.

infiltration: movement of water from the surface into the soil.

ion: electrically charged atom or group of atoms.

jarosite: ochre-yellow or brown hydrous iron sulphate mineral ($KFe_3(SO_4)2(OH)_6$).

jungle: Sanskrit word to describe an area of dense or impenetrable vegetation, nowadays associated with the tropical rainforest biome.

karst: topography with sinkholes, caves and underground drainage that is formed by the dissolution of limestone or gypsum.

landslide: the gravitational movement of a mass of rock, debris or soil down a slope. Landslides occur when the condition of a slope changes from being stable to being unstable.

leaching: process by which soluble materials (including **nutrients** and **salts**) in the soil are washed down the soil profile by water.

loess: predominantly silt-sized sediment transported and deposited by wind.

mangrove: family of plants (Rhizophoraceae) that grow in saline coastal **sediments** in the **tropics** and subtropics, also applied to the habitat irrespective of species (e.g. mangrove **swamp**).

marsh: transition zone between water and land, usually covered by grass.

mica: silicate (rich in silica and oxygen) crystalline mineral formed in igneous rocks, constituent of granite.

mineral: an inorganic component derived from rocks.

mineral soil: soil containing less than 20% organic carbon.

monoculture: **agricultural** system that grows a single **crop** over a wide area, often over many years. Highly mechanised, produces large **harvests** and is characterised by large fields. Monocultures are susceptible to spread of diseases. Off-site processing means that residues are not returned to the soil and inorganic **fertilisers** must be applied to maintain soil nutrient levels. Opposite system is polyculture.

mycorrhiza: fungal hyphae that makes a symbiotic association with plant roots, acting as an extension of root system and thus aiding plant development and soil condition.

nitrate: ion with the formula NO^{3-}, base of nitric acid. Combines to form highly soluble salts (e.g. sodium nitrate, $NaNO_3$). Occurs in urine and also produced by a certain bacteria. Key constituent of fertilisers. Synthetically produced nitrates are key ingredients of fertilisers and pollutants responsible for eutrophication of water bodies.

nitrogen: chemical element with symbol N and atomic number 7. Colourless, odourless inert gas at standard conditions. Basis for many compounds (e.g. ammonia, nitric acid, nitrous oxide, urea). Occurs in all living organisms in amino acids.

no till: a procedure whereby a crop is planted directly into the soil without **ploughing** after the harvest of the previous **crop**. A special planter is necessary to prepare a narrow, shallow seedbed immediately surrounding the seed being planted. Protects soil from **erosion** and increases **organic matter** levels. Also known as **zero tillage**. Used in **conservation agriculture**.

nutrient: essential element needed by plants and animals to build biomass. Classed as macronutrients if needed in large quantities (primarily **nitrogen**, **phosphorus**, **potassium**, calcium, magnesium and sulphur) or micronutrients if needed in very low quantities (primarily boron, chlorine, copper, iron, manganese, molybdenum and zinc).

organic: relating to an organism, living material.

overland flow: water that travels across the surface of the soil, either when soil is **saturated** or rainfall exceeds **infiltration** rate. Also known as **runoff**.

oxide: chemical compound that contains at least one **oxygen** atom and one other element (e.g. NO nitrous oxide, CO_2 carbon dioxide). Most metal ore deposits are actually oxides (e.g. the iron ore haematite, Fe_2O_3).

oxidation: the addition of oxygen, removal of hydrogen or the removal of electrons from an element or compound. Soil organic matter is oxidised to more stable substances. Opposite of **reduction**. Oxidation of iron is referred to as rusting.

pan: a well-defined, hardened layer in the soil. **Plough** pan builds up just below the depth of **tillage** while iron pan forms by the accumulation of iron **oxide**. Can impede the passage of water through the soil.

parent material: mineral or rock material on and/or from which soils are formed.

pasture: grassland used for grazing animals.

peat: organic soil consisting of decayed or partially decayed humified plant remains in swampy or water-logged areas, where oxygen is absent. Peat-covered terrain is often referred to as **peatland**.

ped: an individual natural soil aggregate.

pedogenesis: process of soil formation and development.

pedology: the scientific study of soil.

pedon: three-dimensional body of soil with lateral dimensions (1 to 10 m^2) large enough to permit the study of shapes and relations of horizons.

permanent grassland: natural or agricultural land with grass cover, not ploughed.

ploughing: mechanical cultivation of soils by the plough to different depths, creating arable land.

permafrost: ground (soil or rock and included ice and organic material) that remains at or below 0°C for at least two consecutive years.

permeability: a measure of the ease with which fluids, gases or plant roots can travel through soil.

pH: a measure of acidity, measured from 1 (acid) through 7 (neutral) to 14 (alkaline). Most soils fall in a range between pH 4 to 8.

phosphorus: a highly reactive, non-metalic element with symbol P and atomic number 15. Phosphorus is never found as a free element on Earth. Essential for life as it is a component of DNA and cell membranes. Low phosphate levels limit growth in plants. Major component of fertilisers as it is needed to replace the phosphorus removed from the soil by harvested plants and boost **yields**. Highly bound to some soils, especially in tropics. Also used in pesticides.

photosynthesis: process by which plant cells use the sun's energy to join carbon dioxide and water to make sugar, the food of green plants.

pollution: introduction of contaminants into the natural environment that cause undesirable changes, causes stress to organic systems and can result in death of organisms depending on susceptibility or dose. Can affect human health and soil functions.

pore: the space between soil **aggregates** or soil particles. Also referred to as pore space.

porosity: a measure of the volume of **pores** in a soil, expressed as a fraction for a given volume of soil.

potassium: chemical element with symbol K and atomic number 19. Essential for life and occurs in high concentrations in plants and fruits. Intensive crop production rapidly depletes soils of potassium. **Agricultural fertilisers** account for almost all global production of potassium.

precipitation: water reaching the ground in the form of rainfall, snow or hail.

pyrite: commonly occurring, pale-bronze or brass-yellow mineral, iron sulphate (FeS_2): also known as 'fool's gold'.

quartz: resistant crystalline mineral consisting of silicon and oxygen (SiO_2). Second most abundant mineral in the Earth's crust. Major component of granite, sand (Arenosols), many tropical soils (e.g. Ferralsols) and many sedimentary deposits.

quaternary: a geological time period extending from 1.8 million years ago to present time; incorporates both the Pleistocene and Holocene epochs.

rainforest: **forest** characterised by high rainfall, normally >2000 mm, can be **tropical** or **temperate**.

reduction: the addition of **hydrogen**, removal of oxygen or the addition of electrons to an element or compound. Under anaerobic conditions (such as in waterlogged soils), sulphur compounds are reduced to odour-producing hydrogen sulphide (H_2S). Reduction is the opposite of oxidation.

regolith: unconsolidated mantle of weathered rock and soil material on the Earth's surface.

rhizosphere: zone immediately adjacent to plant roots in which levels of microorganisms can be significantly higher than that of the soil body.

root exudates: carbohydrates, organic acids, vitamins and other substances released from roots.

runoff: see **overland flow**.

saline soil: soil containing sufficient soluble salt to adversely affect the growth of most crop plants.

saturation: when soil pore space is completely full of water, may give rise to **overland flow**.

sand: soil particles between 0.05 mm and 2 mm.

sediment: mineral or organic material that has been transported by wind or deposited in water (such as lakes or the sea). Basis for sedimentary rocks such as sandstone, chalk and shale. See **alluvium**.

shifting cultivation: form of **agriculture** in which cultivated area is abandoned after a few years to allow soil properties to recover under natural re-growth.

silica: name for chemical compound silicon dioxide, (SiO_2). Silica is a resistant substance and is most commonly found in nature as sand or quartz

smectite: a 2:1 type **clay mineral** with a high **cation exchange capacity**.

sodic soil: soil with excess of sodium (pH is usually in the range 8 – 10) that are not used for agriculture.

sodium: a chemical element with symbol Na and atomic number 11. A soft, silvery-white, highly reactive alkali metal. Sixth most abundant element in the Earth's crust and component of numerous minerals (e.g. feldspars, rock salt). Produces highly soluble salts that are easily leached in soil.

soil compaction: a decrease in the volume of pore space between soil particles or aggregates. Severely compacted soil can become impermeable.

soil degradation: process that leads to a deterioration of soil properties and functions, often accelerated by human activities.

soil depth: depth of soil profile from the top to parent material or bedrock or to the layer of obstacles to roots.

soil fertility: measure of the ability of soil to provide a sufficient amount of nutrients, water and a suitable medium for healthy plant growth.

soil function: any service, role or task that soil performs, especially sustaining biological activity (agriculture); regulating and partitioning water and solute flow; filtering, buffering, degrading and detoxifying pollutants; storing and cycling of nutrients; providing support for buildings and other structures; protecting cultural heritage.

soil microorganisms: very small life-forms, represented by protozoa, viruses, bacteria, fungi and algae.

soil organic matter: **carbon**-containing compounds of the soil exclusive of undecayed plant and animal residues. See **humus**.

soil productivity: the capacity of a soil to produce a certain **yield** of a **crop** under a specified farming system.

soil profile: vertical section through soil, often from parent material, showing the arrangement of horizons.

soil quality: quantitative or qualitative measure used to estimate the capacity of a soil to deliver a specific **function**, often expressed in biological, chemical or physical terms.

soil sealing: covering or destruction of soil by urban fabric or artificial material which may be impermeable to water (e.g. asphalt or concrete). Soil sealing can cause rapid **overland flow** after **precipitation** where water cannot soak away, leading to potential flooding.

soil structure: the aggregation of soil particles into units separated from each other by surfaces of weakness.

soil texture: numerical proportion of sand, silt and clay in a soil. Texture can be coarse (sand particles predominate), medium (silt particles predominate) or fine (clay particles predominate).

sorption: a physical or chemical process by which one substance becomes attached to another

swamp: seasonally flooded low land. Similar to **marsh**, but with more woody plants and to **bog** but with better drainage.

swelling and shrinking: swelling – increase of soil volume, shrinking – decrease of soil volume. Processes influenced by water content and the nature of clay minerals.

silt: soil particles between 0.002 mm and 0.05 mm.

tertiary: a period of time between sixty five and three million years ago, prior to the **quaternary** period.

temperature: describes the warmth or coldness of an object.

thawing: melting of the ice as a result of a rise in temperature.

tillage: see ploughing.

topsoil: dark-coloured surface layer of soil containing decomposing organic matter, usually high in nutrients.

tropic: line that marks the northernmost and southernmost latitudes (23° 26' 16") at which the sun may be seen directly overhead (Tropic of Cancer and Capricorn respectively).

tropics: area of land around the Equator bounded by the Tropics of Cancer and Capricorn, often associated with climate that is warm to hot and moist all year round, although this is not always the case.

tropical: relating to the tropics, often with the sense of lush vegetation and a hot, humid climate.

temperate: climatic zone that lies between the **tropics** and the polar regions characterised by moderate temperatures and precipitation, can become more extreme with distance from the ocean. Limited in Africa to northern and southern coastal areas.

vermiculite: highly charged 2:1 clay mineral, formed from mica.

wasteland: land not capable of, or suitable for, producing materials or services of value (e.g. **crops**).

water capacity, available (AWC): amount of water available for plants to use. Volume of water released from soil between the time the soil is at field capacity until the time it is at the wilting point. Loamy soils and soils high in organic matter have the highest AWC.

water capacity, retention (WHC): ability of soil to hold water for a period that is longer than infiltration, also known as water holding capacity.

water table: upper level of groundwater.

waterlogging: soil that is very wet, most pore spaces are filled with water (saturation). The opposite is an aerated soil.

weathering: breakdown of rocks by a combination of biological, chemical, and physical agents.

weed: vague term to define unwanted plants in human-controlled settings where it may be in competition with other plants (i.e. crops) for water and nutrients, or may interfere with harvests. Often denotes plants that grow and reproduce aggressively and invasively.

wetland: land that is normally inundated or saturated by groundwater (e.g. bog, swamp, marsh). Characterised by distinctive vegetation communities that can tolerate wet conditions and peaty or gleyic soils.

wilting point: occurs when water is held too tightly in soil for plants to extract.

yield: the amount of a specified crop (e.g. maize, coffee beans) produced per unit area. Usually expressed in kg or tonnes per hectare.

zero tillage: See no-till.

Further reading

If you want to learn more about soil, then we would suggest investing in a general textbook (see #7, 7a below). If you are interested in obtaining more information on the material presented in the atlas, then the following sources are proposed. The numbers of the references listed below refer to the bracketed numbers in the text of the atlas (e.g. [6]). All urls were checked in March 2013.

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Contacts

Soil contacts in specific countries

If you are interested in learning more about the soil of a specific country, a list of contact persons and organisations is available on the European Commission Joint Research Centre Web Page for the Soil Atlas of Africa:

http://eusoils.jrc.ec.europa.eu/library/maps/africa_atlas/index.html

Other international organisations with an interest in soil in Africa

International Center for Tropical Agriculture (CIAT)
Regional Office in Africa
c/o International Centre of Insect Physiology and Ecology
Duduville Campus Off Kasarani Road
P.O. Box 823-00621
Nairobi, Kenya
http://webapp.ciat.cgiar.org

World Agroforestry Centre (ICRAF)
Headquarters
United Nations Avenue, Gigiri
PO Box 30677
Nairobi, 00100, Kenya
http://www.worldagroforestrycentre.org/

Tropical Agriculture and Rural Environment Program
Columbia University, Lamont Campus
61 Route 9W, Lamont Hall, 2G
P.O. Box 1000
Palisades, NY 10964, USA
http://tropag.ei.columbia.edu/

International Institute of Tropical Agriculture (IITA)
PMB 5320, Ibadan, Oyo State
Nigeria
International mailing address:
IITA, Carolyn House, 26 Dingwall Road, Croydon CR9 3EE, UK
http://www.iita.org/

The FAO in Africa

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FAO Building
2 Gamel Abdul Nasser Road
Accra, Ghana
Tel: +233-(0)302 675000/7010930
Email: fao-ro-africa@fao.org

Sub-Regional Office for North Africa
43 Rue Kheireddine PACHA
Belvédère, Tunis, Tunisia
Tel:+216-71-906553
Email:FAO-SNEA@fao.org
Web: http://neareast.fao.org/

Sub-Regional Office for West Africa
Gamel Abdul Nasser Road
Accra, Ghana
Tele: +233-21-2675000
Email: FAO-SFW@fao.org
Web: http://www.fao.org/africa/west/

Sub-Regional Office for Central Africa
Villa N° 36 Cité de la Démocratie
Libreville , Gabon
Tél: (+241) 77 47 83
Email: FAO-SFC@fao.org
Web: http://www.fao.org/africa/central

Sub-Regional Office for Eastern Africa
CMC Road Near ILRI
Bole Sub City, Kebele 12/13
Addis Ababa, Ethiopia
Tel: +251-11-647 8888
Email: FAO-SFE@fao.org
Web: http://www.fao.org/africa/sfe/en/

Sub-Regional Office for Southern Africa
Block 1, Tendeseka Office Park
Corner Samora Machel Avenue & Renfrew Road
Eastlea, Harare, Zimbabwe
Tel: +263-4-253655
Email: FAO-SFS@fao.org
Web: http://coin.fao.org/cms/do/en/office.html?officeCode=SFS

The European Union and Africa

The Joint Africa-EU Strategic Partnership

The Joint Africa-EU Strategy (JAES) outlines a long- term shared vision of the future of Africa-EU relations in a globalised world. It addresses:

- Development cooperation, by opening up the EU-Africa dialogue to issues of joint political concern and interest;
- Moving away from a focus on African matters only and openly addressing European and global issues;
- Support for Africa's aspirations to find regional and continental responses to some of the most important challenges;
- Mechanisms to ensure a better participation of African and European citizens, as part of an overall strengthening of civil society in the two continents.

During the second Africa-EU summit, held in Lisbon in December 2007, African and European leaders adopted the proposal for the Africa-EU Strategic Partnership. The Partnership provides a mechanism for the EU to address Africa as a single entity and constitutes a platform to help improve the coordination, coherence and consistency of the EU's policies and instruments towards Africa with those of its Member States. Based on this shared vision and on common principles, the JAES defines eight specific partnership themes, namely:

- Peace and security;
- Democratic governance and human rights;
- Trade, regional integration and infrastructure;
- Millennium Development Goals (MDGs);
- Energy;
- Climate change;
- Migration, mobility and employment;
- Science, information society and space.

The final communication of the 3rd Africa-EU Summit, (held in Tripoli in November 2010) renewed the commitment towards the partnerships and outlined an Action Plan for economic development, peace and security and the attainment of the Millennium Development Goals in Africa by 2015.

The participants emphasised the link between stronger economic cooperation and regional integration. They highlighted the importance of increased private sector engagement in translating political objectives into concrete results. The Final Communication also called for increased cooperation in the fields of science and information technology to create a more inclusive knowledge-based and globally competitive economy.

For more information, please visit:

http://www.africa-eu-partnership.org/

Soil in the context of the Second Joint Africa-EU Action Plan (2011-2013)

While not specifically discussed, the efficient and sustainable use of soil is at the heart of several of the partnerships defined under the Second Joint Africa-EU Action Plan. These include:

Partnership 3: Regional Integration, Trade and Investment are the foundation blocks of economic stability and sustainable growth. As this atlas has shown, the economies of many African countries are based on agriculture. Consequently, good land management and care of soil resources are implicitly integral to this issue. Investment in capacity building, governance and infrastructure is critical.

Partnership 4: As described in the introduction to this atlas, soil fertility is at the heart of most of the **Millennium Development Goals** (MDG). The Action Plan aims to accelerate progress towards the attainment of all the MDGs in Africa by 2015. As they are interlinked and mutually dependent, reinforcing an understanding of African soil resources and promoting a culture of soil preservation will ensure progress in achieving targets in areas such as food security, health and environmental stability. In this context, the implementation of the Africa Union Commission's African Land Policy Guidelines are important. Capacity building in soil science is critical to support the development of the African agricultural sector.

Partnership 6: Soil is an important component of both **climate change and sustainable environmental development**. With regard to climate change, the soils of Africa are a significant carbon sink and can play an active role in both mitigation and adaptation measures. Reducing emissions from deforestation and forest degradation should lead to improvements in soil quality. The implementation of the 2nd phase of the Great Green Wall for the Sahara and the Sahel Initiative (GGWSSI) will lead to increased soil organic matter and water retention along the southern edge of the Sahara.

Partnership 7: With respect to **migration, mobility and employment**, European Union institutions can play a significant role in the mobility of students and academics studying soil science through initiatives such as the Eramus Mundus programmes and the Pan-African University.

Partnership 8: Actions focusing on **Science, Information Society and Space**, especially in relation to capacity building. The assessment of soil state and monitoring of trends, will result in faster economic growth and social development in Africa. The resulting knowledge-generating/knowledge-based economy will help further address the major common problems and global challenges.

The EU and Africa

The European Union contributes actively to help developing countries stand on their own two feet. By tackling poverty, boosting local economies and strengthening governance, the EU support millions of people across Africa. The EU provides assistance in a way that secures the long-term future of developing countries which face the rigours of operating in an ever more complex and fast-paced global economy. In fact the EU (27 Member States and the European Commission) is the largest provider of development aid to Africa (in 2010, the EU provided more than half of global official development assistance).

The European Commission finances most of its development programmes for African partner countries through the European Development Fund (EDF). The Commission also funds some programmes from the EU's general budget. Member States contribute to both the EDF and the general budget.

Support top Africa is significant: in 2010, the European Commission dedicated around 42% of its disbursed aid to Africa (EUR 4.1 billion) with North Africa receiving €534 million and Sub-Saharan Africa receiving €3,554 million. The tenth EDF runs from 2008 to 2013, and is scheduled to give out payments of €22.7 billion. The national and regional programming for Africa for 2008-2013 amounts to €13.9 billion.

This aid is made available through various instruments and channels (projects and sector-wide approach, budget support, NGOs and multilateral institutions such as the World Bank and the United Nations). Funding is flexible and goes where it is needed (e.g. health and education, infrastructure projects and budget support).

Africa is also covered by the European Neighbourhood and Partnership Instrument (for the Mediterranean countries), the geographic part of the Development Cooperation Instrument (DCI), which applies to South Africa and by worldwide thematic instruments such as the European Instrument for Democracy and Human Rights (EIDHR) or the thematic programmes of the DCI (Investing in People, Migration and Asylum).

For further information, please visit the web site of the European Commission's Directorate-General Development and Cooperation – EuropeAid:

http://ec.europa.eu/europeaid/

The European External Action Service is the European Union's diplomatic corps. It supports the EU foreign affairs chief (High Representative for Foreign Affairs and Security Policy, Catherine Ashton) in conducting the common foreign and security policy. It has over delegations in forty-seven African countries.

http://ec.europa.eu/world/where/index_en.htm#7

The European Commission

The European Commission (EC) is the EU's executive body and represents the interests of Europe as a whole (as opposed to the interests of individual countries).

The term 'Commission' refers to both the college of commissioners and the institution itself – which has its headquarters in Brussels, Belgium. The Commission's main roles are to:

- set objectives and priorities for action;
- propose legislation to Parliament and Council;
- manage and implement EU policies and the budget;
- enforce European Law (jointly with the Court of Justice);
- represent the EU outside Europe (negotiating trade agreements between the EU and other countries, etc.).

Some 23 000 staff members work in the Commission in departments, known as directorates-general (DGs) or services, each responsible for a particular policy area and headed by a Director-General, who reports directly to the President. The DG Joint Research Centre is the Commission's in-house science service (see page 172).

José Manuel Barroso, President of the European Commission and Nkosazana Dlamini-Zuma, Chairwoman of the African Union Commission in Addis Ababa during the 6th EU/African Union Commission meeting in April 2013. The next EU/Africa Summit is foreseen to take place in April 2014. (EC)

The European Union

The European Union (EU) is an economic and political association of European countries with a combined population of over 500 million inhabitants (7.3% of the world population) and an economy representing approximately 20% of global Gross Domestic Product (GDP). The EU has evolved from the original six countries of the European Coal and Steel Community (1951) and the European Economic Community (1958), to 27 Member States. The term 'European Union' was established under the 1993 Maastricht Treaty. The EU is represented at the United Nations, the WTO, the G8 and the G20.

The EU operates through a system of supranational independent institutions and intergovernmental negotiated decisions adopted by the Member States. Important institutions of the EU include the European Commission, the Council of the European Union, the Court of Justice of the European Union, and the European Central Bank. The members of the European Parliament are elected every five years by EU citizens.

http://ec.europa.eu/

The African Union

The African Union

The African Union (AU or UA in French) is a political association of fifty-four African states that was established on July 9th 2002 as a successor to the Organisation of African Unity (OAU).

Vision of the African Union

The vision of the African Union is of an integrated, prosperous and peaceful Africa, driven by its own citizens and representing a dynamic force in the global arena.

The main objectives of the AU are to:

- achieve greater unity and solidarity between the African countries and the peoples of Africa;
- defend the sovereignty, territorial integrity and independence of its Member States;
- accelerate the political and socio-economic integration of the continent;
- promote and defend common African positions on issues of interest to the continent and its peoples;
- encourage international cooperation, taking due account of the Charter of the United Nations and the Universal Declaration of Human Rights;
- promote peace, security, and stability on the continent;
- promote democratic principles and institutions, popular participation and good governance;
- promote and protect human and peoples' rights in accordance with the African Charter on Human and Peoples' Rights and other relevant human rights instruments;
- establish the necessary conditions which enable the continent to play its rightful role in the global economy and in international negotiations;
- promote sustainable development at the economic, social and cultural levels as well as the integration of African economies;
- promote cooperation in all fields of human activity to raise the living standards of African peoples;
- coordinate and harmonise the policies between the existing and future Regional Economic Communities for the gradual attainment of the objectives of the Union;
- advance the development of the continent by promoting research in all fields, in particular in science and technology;
- work with relevant international partners in the eradication of preventable diseases and the promotion of good health on the continent.

The African Union is made up of both political and administrative bodies. The highest decision-making organ is the Assembly of the African Union which is composed of Heads of State and Government (or their duly accredited representatives). The Assembly of Heads of State and Government is the supreme organ of the African Union.

At the time of publication, the Assembly is chaired by Yayi Boni, president of Benin. Other political institutions of the AU include:

The **Executive Council** is composed of Ministers (or Authorities designated by the Governments) of Member States. The Executive Council answers to the Assembly.

The emblem of the AU

The emblem of the AU is shown adjacent to the flag at the top of this column and on the cover of the atlas.

The red interlinked rings stand for African solidarity and the blood shed for the liberation of Africa while the palm leaves represent peace. The gold colour stands for Africa's wealth and a bright future, the green is for African hopes and aspirations. To symbolise unity, the silhouette of Africa is drawn without internal borders.

The Commission (see text in adjacent column).

The **Permanent Representatives Committee** is composed of Permanent Representatives (i.e. ambassadors) of Member States accredited to the Union. The Permanent Representatives Committee is charged with the task of preparing the work of the Executive Council.

The protocol for the **Peace and Security Council (PSC)** is in the process of ratification and aims to be a mechanism for the prevention, management and resolution of conflicts and crisis situations in Africa.

The **Pan-African Parliament (PAP)** is the legislative body of the African Union. The PAP has both advisory and consultative powers. The Parliament is composed of 265 representatives that are elected by the legislatures of the AU member states every five years. Initially based in Addis Ababa (Ethiopia), the PAP now resides in Midrand, South Africa. The Pan-African Parliament created ten **Specialised Technical Committees** at Ministerial level to address various sectorial issues across the continent. They include Rural Economy and Agricultural Matters; Monetary and Financial Affairs; Trade, Customs and Immigration; Industry, Science and Technology, Energy, Natural Resources and Environment; Transport, Communications and Tourism; Health, Labour and Social Affairs; and Education, Culture and Human Resources.

The **Economic, Social and Cultural Council (ECOSOCC)** is an advisory body designed to give civil society organisations (e.g. workers unions, business and professional groups, service providers, policy think tanks, etc.) a voice within the AU institutions and decision-making processes.

The **Court of Justice** is the principal judicial body of the Union with authority to rule on disputes over the interpretation of AU treaties. In 2008, a decision was taken to create an African Court of Justice and Human Rights with added powers for rulings on the human rights treaties. The court will be based in Arusha, Tanzania.

Financial Institutions including the African Central Bank (Abuja, Nigeria), the African Investment Bank (Tripoli, Libya) and the African Monetary Fund (Yaoundé, Cameroon) are foreseen but have not yet been established. Eventually, the AU aims to have a single currency (the Afro).

The **main administrative capital of the African Union is Addis Ababa**, Ethiopia, where the African Union Commission has its headquarters.

For more information on the AU, please visit:

http://www.au.int/

The African Union

Membership of the AU

- All independent countries in Africa and African island states, as well as Western Sahara, are, or have been, members of the AU. At the time of publication, there are fifty-four members.
- Morocco left unilaterally in 1984, when the majority of member countries supported the entry of the Sahrawi Arab Democratic Republic (Western Sahara) to the AU. Morocco continues to have a special status within the AU and Moroccan delegates participate at important AU functions. Negotiations continue to try to resolve the issue.
- At the time of publication, Madagascar (since 2009) and Guinea-Bissau (since 2012) are suspended.
- The official languages of the AU are Arabic, English, French Portuguese, Spanish and Swahili. However, "any other African language" can be used as a working language.
- Gold and green (sometimes together with white) are promoted as the "national colours" of Africa.
- In 2011, the IMF estimated that the combined states of the African Union constitute a nominal GDP of US$ 1 627 trillion.

The member states of the African Union. Suspended states are highlighted in light green (status at the time of publication). Morocco is currently not a member of the African Union. (WikiH)

The AU Commission

The African Union Commission (AUC) is the Secretariat of the Union and is entrusted with executive functions. It is composed of a Chairperson, a Deputy Chairperson, eight Commissioners and staff members. Positions are normally held for four years.

The AUC represents the Union and protects its interests under the auspices of the Assembly of Heads of State and Government as well as the Executive Council.

The AU Commission is made up of portfolios. They are: Peace and Security; Political Affairs; Trade and Industry; Infrastructure and Energy; Social Affairs; Rural Economy and Agriculture; Human Resources, Science and Technology, and Economic Affairs.

The current Chair of the AUC (since 17 July 2012) is Mrs Nkosazana Dlamini-Zuma (South Africa) who is also the first female head of the AUC. Mr Erastus Mwencha (Kenya) is the incumbent Deputy Chairperson.

Mission of the African Union Commission

An efficient and value-adding institution driving the African integration and development process in close collaboration with African Union Member States, the Regional Economic Communities and African citizens.

Department of Rural Economy and Agriculture

The issues described in this atlas fall predominantly under the remit of the AUC's Department of Rural Economy and Agriculture which is under the guidance of Her Excellency Tumusiime Rhoda Peace.

The Department of Rural Economy and Agriculture (DREA) was established with the aim of promoting agricultural and rural development and ensuring food security for Africans. These goals are coupled with achieving sustainable development and improved livelihoods for the population while ensuring effective protection and development of the African environment. These targets are underpinned by sound environmental and natural resources management including disaster risk reduction and adaptation to climate change.

The DREA is divided into three competence areas: the Agriculture and Food Security Division, the Environment and Natural Resources Division and the Rural Economy Division.

African Economic Community

The African Economic Community (AEC) is an organisation of African Union states established to extend mutual economic development through the creation of free trade areas, customs unions, a single market, a central bank and a common currency.

Currently there are multiple regional blocks in Africa, known as Regional Economic Communities (RECs), many of which have overlapping memberships.

See maps on pages 70 – 79.

The Joint Research Centre

European Commission

A research-based policy support organisation

The JRC is a Directorate-General of the European Commission under the responsibility of Máire Geoghegan-Quinn, European Commissioner for Research, Innovation and Science. The JRC provides scientific advice and technical know-how to support a wide range of European Union (EU) policies. More than 25% of EU legislation has a technical or scientific basis and this trend is likely to grow as policies increasingly cut across several disciplines. The JRC, as the Commission's in-house research-based policy support centre, works to provide such support throughout the policy process, while maintaining a strong science base. Its status as a Commission service, which guarantees independence from private or national interests, is crucial for pursuing its mission.

The JRC has seven scientific institutes, located in five different sites situated in Belgium, Germany, Italy, the Netherlands and Spain, with a wide range of laboratories and unique research facilities. Through numerous collaborations, access to many facilities is granted to scientists from partner organisations. Employing around 2,750 staff from all over the EU, the JRC has an annual budget of €330 million. Further income is generated through the JRC's participation in Framework Progamme projects, additional work for Commission services and contract work for third parties, such as regional authorities and industry. The latest figures are available in the JRC's annual report.

http://www.jrc.ec.europa.eu./

JRC Activities

The JRC research programmes are decided by the Council of the European Union and funded by the EU budget with additional funding from associated countries. The JRC multi-annual work programme, running from 2007 to 2013, focuses on clearly defined themes, reflecting a coherent approach to user needs.

JRC value statement

"The JRC aims to operate to the highest standards of quality, efficiency and integrity with respect to the society as a whole, to its customers and to its own staff." Our work ranges from detecting and measuring genetically modified organisms (GMO) in food and feed to developing nuclear forensics technology for combating illicit trafficking of nuclear material and to using satellite technologies for monitoring land use and emergency situations such as forest fires and floods. Our activities also involve the definition of food safety standards, research into new energy technologies and evaluating policy options, for instance related to climate change.

Communicating the importance of soil to school children during a recent Open Day at the JRC site in Ispra. (EA)

JRC mission statement

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle. Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners. Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security, including nuclear; all supported through a cross-cutting and multi-disciplinary approach.

The main customers of the JRC are the policy making Directorates General of the European Commission. Depending on the subject matter, the JRC's scientific-technical support covers the complete policy cycle or parts of it: the JRC anticipates policy needs, assesses policy options and their impacts, and monitors and contributes to the implementation of policies. It also provides operational support in certain cases, for example in anticipating environmental disasters, providing assistance to managing crises and assessing any consequential damage and their impact on human life and/or the environment. The ultimate beneficiaries of these activities are the EU Member States.

In July 2010, the JRC published its strategy for 2010 - 2020 with the intention to focus its efforts on seven thematic areas, which respond to major EU and global challenges and take into account the JRC's proven competences:

- Towards an open and competitive economy;
- Development of a low carbon society:
- Sustainable management of natural resources;
- Safety of food and consumer products;
- Nuclear safety and security;
- Security and crisis management;
- Reference materials and measurements

In keeping with its mission, the JRC strives to play a role as a centre of reference in its key competence areas through extensive networks with the relevant organisations in the Member States and, where appropriate, international organisations. In addition to these institutional activities, the JRC co-operates closely with external organisations. In line with a strategic approach to the JRC's role as a partner, several high level agreements have been set up with large scientific and industrial communities on new networks and research collaboration.

The seven scientific institutes and headquarters of the JRC. (JRC)

Institute for Environment and Sustainability
European Commission
Joint Research Centre
Via Fermi
21027 Ispra (VA)
Italy

http://ies.jrc.ec.europa.eu/

The Institute for Environment and Sustainability

The mission of the Institute for Environment and Sustainability is to provide scientific and technical support to the EU policies for the protection of the environment and the more efficient and sustainable management of natural resources at global and continental scales.

The Institute for Environment and Sustainability (IES) is one of the seven scientific research institutes of the European Commission's JRC.

Located in Ispra, Italy, the IES carries out research to understand the complex interactions between human activity and the physical environment, and how to manage strategic resources (water, land, forests, food, minerals, etc.) in a more sustainable manner. Together with other JRC institutes, the IES provides the scientific basis for the conception, development, implementation and evaluation of EU policies that promote the greening of Europe and the global sustainable management of natural resources. It also works in partnership with other Directorates General to support the strategic priorities of the European Commission.

The Institute brings together multi-disciplinary teams who work with observations and numerical analyses, and develops the ICT infrastructures necessary to share data and models. It combines this in-house expertise with its role as a scientific catalyst in order to provide the knowledge base necessary to assess the social, environmental and economic aspects of policy options. The IES plays an active role in partnerships within the EU and global scientific communities, which are a prerequisite for finding sustainable solutions to today's global environmental challenges.

The Soil Atlas of Africa is a striking example of the type of high level output generated by the Institute for Environment and Sustainability. By bringing together scientists from both Africa and Europe, the atlas illustrates the benefits of international collaboration and the need for scientifically sound policies for the sustainable management of a key natural resource that is the cornerstones of food security, key environmental services, social cohesion and the economies of most African countries.

Dr. Maria Betti

Director
Institute for Environment and Sustainability

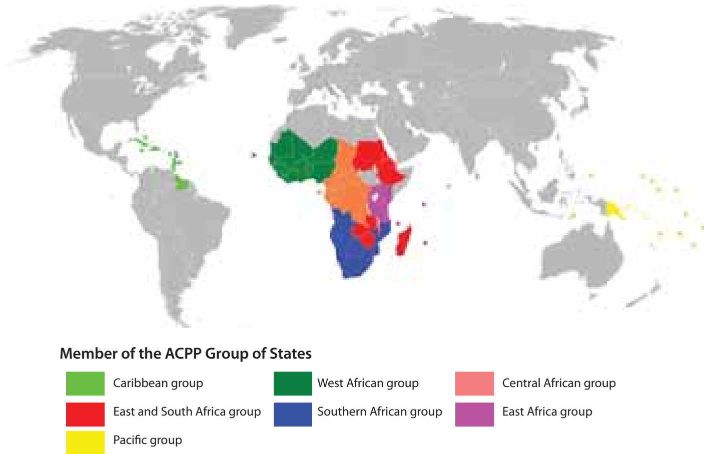
Soil in the JRC

The development of this atlas was undertaken by the IES Soil Action, which is part of the Land Resource Management Unit.

The Soil Action provides a single focal point for soil data and information for the European Commission and other EU institutions. The Soil Action maintains the European Soil Data Centre and provides high-level analysis and assessments on the status and trends of soils in Europe and other parts of the world. The Action is staffed by a team of soil scientists, agricultural scientists, geographers, geologists, IT specialists and modellers. There is a strong competence in soil science, spatial analysis and geostatistics.

Soil Action Leader: Luca Montanarella

http://eusoils.jrc.ec.europa.eu/



The ACP Group of States

The African, Caribbean and Pacific Group of States (ACP) was created by the Georgetown Agreement in 1975. It is composed of 79 African, Caribbean and Pacific states, all of which, apart from Cuba, are signatories to the Cotonou Agreement, also known as the "ACP-EU Partnership Agreement" which binds them to the European Union.

The ACP contains forty-eight countries from Sub-Saharan Africa, sixteen from the Caribbean and fifteen from the Pacific.

The ACP Group´s main objectives are :

- sustainable development of its Member States and their gradual integration into the global economy, which entails making poverty reduction a matter of priority and establishing a new, fairer, and more equitable world order;
- coordination of the activities of the ACP Group in the framework of the implementation of ACP-EU Partnership Agreements;
- consolidation of unity and solidarity among ACP States, as well as of understanding among their peoples;
- establishment and consolidation of peace and stability in a free and democratic society.

JRC ACP Observatory Portal

The EU is the world's largest donor of official development assistance, with the European Commission playing an important role in both development policy formulation and the practical aspects of development and aid programme implementation.

The JRC supports various EC services and stakeholders in the ACP Region in a variety of scientific, technical and thematic areas, including sustainable management of natural resources, food security, renewable energies, natural hazards and crisis prevention and management.

Much scientific and technical information underpinning the decision-making processes is often scattered, difficult to access and not comparable. Therefore, it is essential to support the political dialogue with the beneficiaries and to facilitate interaction among different EC services and external partners.

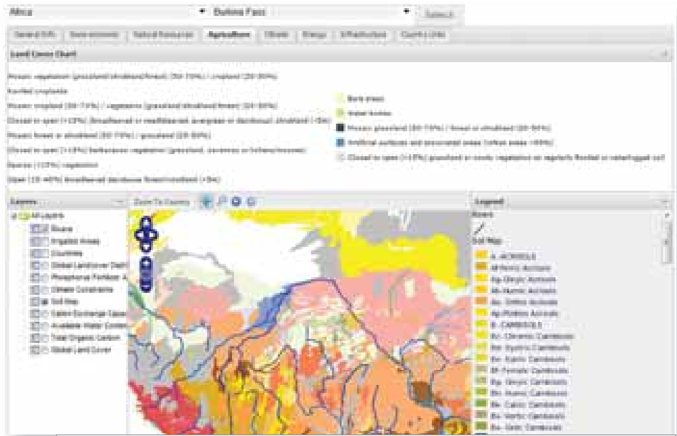
In this context, the JRC has developed an ACP Observatory Portal (i.e. a reference Centre of scientific and technical information) that provides European Commission services and key ACP stakeholders with access to information on themes related to sustainable development in the region. The Portal underpins and supports the development policies and programmes in the areas of sustainable management of natural resources, food security, crisis prevention and renewable energies.

Some of the perils of collecting soil information in Africa! (EM)

The interface of the ACP Observatory is a single interactive web-portal that gives access to information available in the JRC in the different thematic areas.

See http://acpobservatory.jrc.ec.europa.eu/

For each theme (e.g. soil, forest, drylands, agriculture, biodiversity, rangelands, disasters, etc.), the information includes reference maps, indicators, and specific analyses. The ACP Observatory also aims to provide a forward looking tool for the analyses of emerging complex development issues and inter-related scientific topics, such as the link between food security and ecosystem services such as carbon cycling, biodiversity and water quality.



Soil types of the Central African Republic – an example of the maps available on the interactive web-portal of the ACP Observatory. (JRC)

A space-based solution for monitoring land conditions in Sub-Saharan Africa

The operational monitoring of the condition of the land in Africa is essential for policy makers and government agencies. There is an increasing need for environmental information for the implementation of international cooperation policies such as aid distribution and development. To date, decision makers tend to use non-spatial indicators of environmental conditions and human impact. Thus, there is a requirement for new indicators describing the land and vegetation condition. Evidence-based policies need such information.

Satellites provide an operational and cost-effective way to obtain systematic information on the land condition at the continental and regional scale in Africa. The African Monitoring of the Environment for Sustainable Development (AMESD) Programme is a partnership between the European Union and the African Union Commission which extends the operational use of Earth observation data to environmental and climate-monitoring applications.

Motivated by these user demands, the JRC (under the Geoland-2 Project) has developed an environmental monitoring capacity, through the deployment of the eStation (i.e. environmental station) for forty-eight African countries.

The JRC eStation

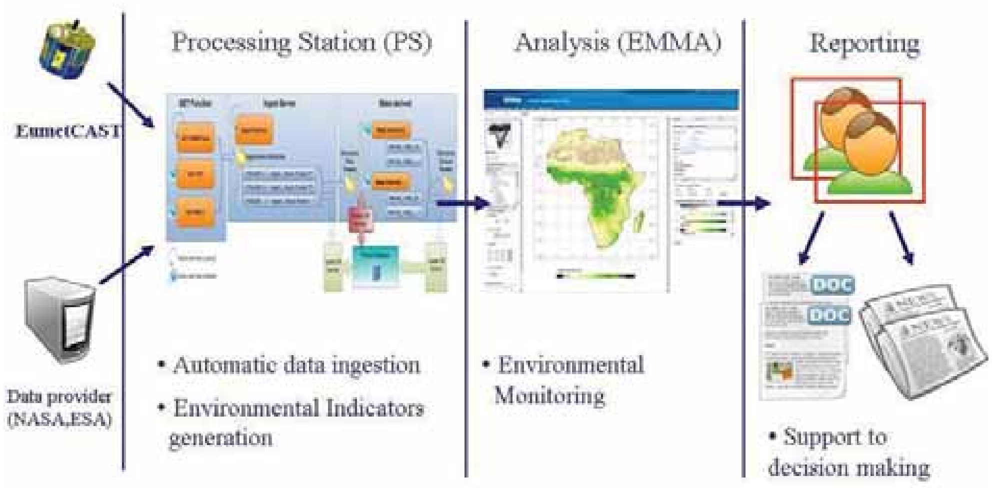
The eStation is an automatic and independent system which automatically collects Earth observation (EO) data, and transforms the original data into a standard format for the computation of temporal synthesis, long term anomalies and 'ad-hoc' environmental indicators.

The eStation hosts a web-based tool, named EMMA (Environmental Mapping & Monitoring for Africa) which displays the products and facilitates ad-hoc analyses.

Vegetation and precipitation time-series analysis in the EMMA interface. (JRC)

For further information, please see:

http://estation.jrc.ec.europa.eu/



The eStation receives and processes earth observation data received from sources such as SPOT-Vegetation, MSG-SEVIRI, Aqua and Terra MODIS and AVHRR. Additionally, background layers to support the analysis include GlobCover Africa 2000, GLC 2000 and a yearly colour composite from SPOT-Vegetation. (JRC)

Key collaborators

The Food and Agriculture Organization

FAO's mandate

Achieving food security for all is at the heart of FAO's efforts - to make sure people have regular access to enough high-quality food to lead active, healthy lives.

FAO's mandate is to raise levels of nutrition, improve agricultural productivity, better the lives of rural populations and contribute to the growth of the world economy.

Its Latin motto, fiat panis, translates into English as "let there be bread". The headquarters of FAO are located in Rome, Italy and the current Director-General is José Graziano da Silva (see preface to atlas).

FAO has 191 Member Nations plus one Member Organization, the European Union and two Associate Members, The Faroe Islands and Tokelau.

FAO's activities comprise four main areas:

- **Putting information within reach.** FAO serves as a knowledge network. We use the expertise of our staff - agronomists, foresters, fisheries and livestock specialists, nutritionists, social scientists, economists, statisticians and other professionals - to collect, analyse and disseminate data that aid development. A million times a month, someone visits the FAO Internet site to consult a technical document or read about our work with farmers. We also publish hundreds of newsletters, reports and books, distribute several magazines, create numerous CD-ROMS and host dozens of electronic fora.
- **Sharing policy expertise.** FAO lends its years of experience to member countries in devising agricultural policy, supporting planning, drafting effective legislation and creating national strategies to achieve rural development and hunger alleviation goals.
- **Providing a meeting place for nations.** On any given day, dozens of policy-makers and experts from around the globe convene at headquarters or in our field offices to forge agreements on major food and agriculture issues. As a neutral forum, FAO provides the setting where rich and poor nations can come together to build common understanding.
- **Bringing knowledge to the field.** Our breadth of knowledge is put to the test in thousands of field projects throughout the world. FAO mobilizes and manages millions of dollars provided by industrialized countries, development banks and other sources to make sure the projects achieve their goals. FAO provides the technical know-how and in a few cases is a limited source of funds. In crisis situations, we work side-by-side with the World Food Programme and other humanitarian agencies to protect rural livelihoods and help people rebuild their lives.

For further information, please visit:

http://www.fao.org

FAO and soil

Soil and FAO are synonymous! Soil resources and their services are essential to food production, enhanced rural development and sustainable livelihoods. The FAO has been providing leadership, technical and policy advice and knowledge on global soil issues, practically since its inception. Apart from providing practical advice to farmers and land owners on techniques for optimising soil resources, the FAO has been collecting and disseminating soil data at a global scale.

As a topic, soil sits within the Land and Water Division of the Natural Resources and Environment Department. The Land and Water Division aims at enhancing the agricultural productivity and advancing the sustainable use of land and water resources through their improved tenure, management, development and conservation. FAO undertakes various activities in the area of land management, land planning and land use.

Specifically, it:

- promotes the development of cost-effective methods for land and soil survey and classification including testing and identification of soil constraints;
- provides documentation, information and technical guidance for the assessment, conservation and productive management of land resources;
- maintains a database and web-based information system on land resources and land use at national and regional level for comparative studies and analysis;
- advises governments and other stakeholders in the formulation and implementation of appropriate land use and land management policies, strategies and action plans.

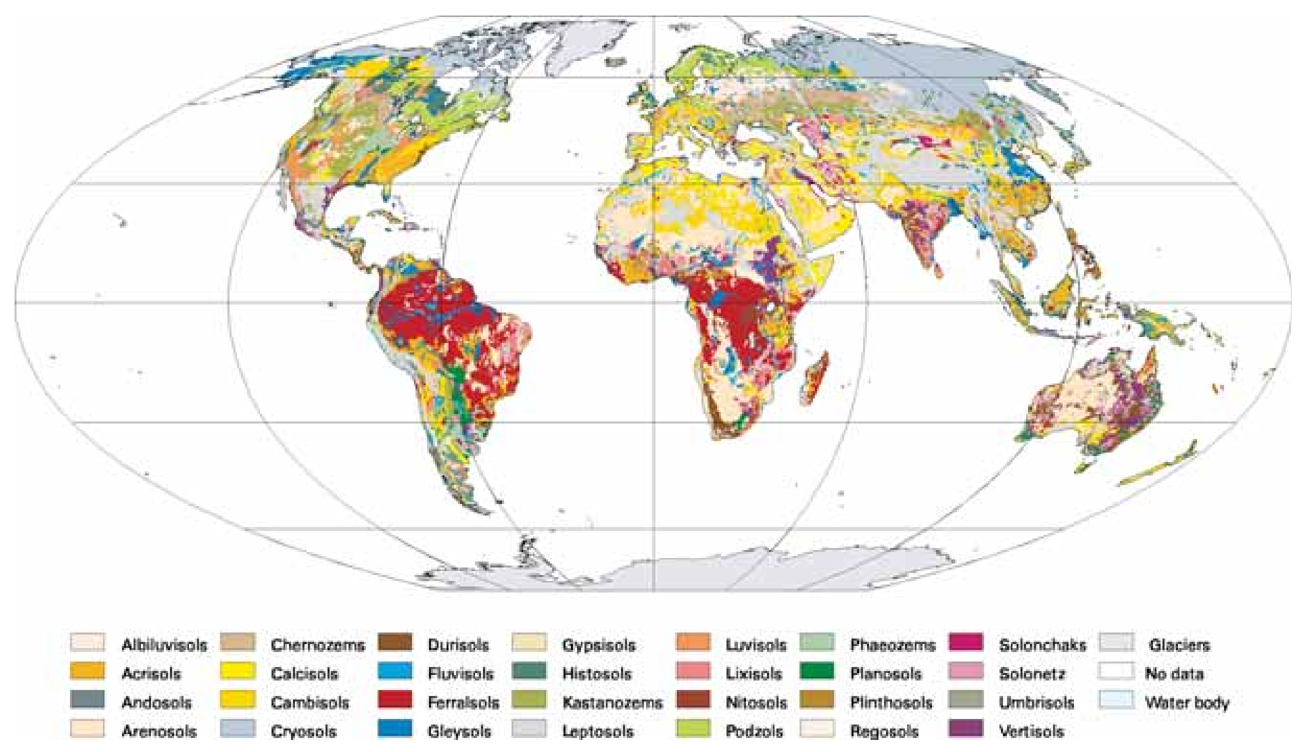
The Land Resources Group holds a large collection of legacy soil maps as well as facilitating access to the Digital Soil Map of the World (see below, the recent Harmonized World Soil Database, Guidelines for Soil Description, Key to the FAO Soil Unites and World Reference Base. In addition, users can consult a multitude of reports, publications and supporting databases, many of which have been used in the making of this atlas.

For further information, please visit:

http://www.fao.org/nr/land/soils/en/

In 1974, the FAO and UNESCO were responsible for the production and publication of the Soil Map of the World at a scale of 1:5 million. Since it's digitisation in 1985, it is still the only harmonised global soil database. The legend has increasingly been used as a national classification system, especially in developing countries, and is now subsumed into the WRB system (see page 50). [97]

For further details and access to the data, please visit:
http://www.fao.org/nr/land/soils/key-to-the-fao-soil-units-1974/en/



The Global Soil Partnership

Soil is a finite natural resource, that on a human time-scale is non-renewable. However, despite the essential role that soil plays in the life of people, there is increasing degradation due to inappropriate practices, population pressures and inadequate governance.

Soils are often perceived as a low priority with no international governance body exists to support a coordinated global action on their management. A unified and authoritative voice for soil management is needed to better coordinate efforts and pool limited resources. For these reasons, the FAO and a group of partners have launched the Global Soil Partnership to improve global governance of the world's soil resources. The Partnership aims to guarantee healthy, productive soils for a food secure world and work together to sustain other essential ecosystem services on which our livelihoods and societies depend.

The Partnership will address five main pillars of action:

1. Promote sustainable management of soil resources for soil protection, conservation and sustainable productivity;
2. Encourage investment, technical cooperation, policy, education awareness and extension in soil;
3. Promote targeted research and development by focusing on identified gaps, priorities and synergies with related productive, environmental and social development actions;
4. Enhance the quantity and quality of soil data and information: data collection (generation), analysis, validation, reporting, monitoring and integration with other disciplines;
5. Harmonisation of methods, measurements and indicators for the sustainable management and protection of soils.

For further information, please visit:

http://www.fao.org/globalsoilpartnership/home/

The FAO in Africa

The FAO has offices throughout Africa. The Regional Office for Africa, located in Accra, Ghana, was opened in 1959 and is responsible for the identification, planning and implementation of the FAO's priority activities across the continent in partnership with Government and other stakeholders. The Regional Office is supported by a series of Sub-regional Offices covering Central Africa (located in Libreville, Gabon), Eastern Africa (Addis Ababa, Ethiopia), North Africa (Tunis, Tunisia), Southern Africa (Harare, Zimbabwe) and West Africa (Accra, Ghana). In addition, the FAO has a Representation Office in 48 African countries.

For further information, please visit:

http://www.fao.org/africa/about-raf/en/

Africa Soil Science Society

The Africa Soil Science Society (ASSS) is a non-profit organisation founded in 1986 following a meeting of African soil scientists who attended the World Soil Congress in Hamburg (Germany). The ASSS has successfully organised five International conferences in Kampala (Uganda, 1988), Cairo (Egypt, 1990), Ibadan (Nigeria, 1994), Accra (Ghana, 2007) and most recently in Yaoundé (Cameroon, 2009).

The objectives of the ASSS are to promote and foster soil science in all its facets and to give support for the collaboration and cooperation amongst the Regional and National Societies of Soil Science in Africa in the pursuit of their activities.

In this perspective, the ASSS aims to promote studies in soil and related sciences to disseminate the acquired knowledge and technology for the benefit of the continent's population. By so doing, the ASSS shall contribute to the promotion of sustainable agricultural production and environmental protection in Africa.

Moreover, the ASSS facilitates information on soil resources for politics, decision makers and for the greater public in Africa, especially in view of sustainable use of natural resources, in particular soil and land. The ASSS also provides leadership in the advancement of soil science in Africa and advise continental Institutions in all matters pertaining to soil science in order to support their influence in the international arena.

As a regional member of the International Union of Soil Sciences (IUSS), the ASSS also aims to promote the effective participation of member societies and of individual African soil scientists in the activities of the IUSS.

The ASSS strongly believes that it is of paramount importance that the role of soils and soil science in ensuring food security and providing other key ecosystem services are given appropriate recognition. These functions and services are fundamental for sustainable production and adaptation to climate variability and climate change.

In this context, the ASSS is committed to:

- Speed up the collection and upscaling of African best practices that could halt or reverse land degradation; reduce risks associated with climate variability; increase the resilience of agriculture and communities to climate change; and promote integrated practices that foster other benefits such as carbon sequestration.
- Further engage ASSS members and other relevant national institutions in generating, improving and disseminating quality soil data for supporting actions and policies, particularly, with regard to land transactions with foreign multinational enterprises.
- Strengthen the role of integrated soil nutrient management and soil quality preservation in national policies and development plans.
- Explore the possibilities for scaling up conservation agriculture principles given their success in some areas as one of the means for promoting the better management of natural resources.

Field visit to a Ferralsol site during the 2009 Congress of the African Soil Science Society in Cameroon. (EVR)

Officers of the ASSS

The current officers of the Executive Bureau were elected at the ASSS conference in Yaoundé in 2009. They are:

- Dr Martin Yemefack (President)
- Dr Robert Zougmoré (Secretary General)
- Dr Hanadi El Dessougi (Vice Secretary General)
- Dr Barrack Okoba (Treasurer)
- Dr. Vide Adedayo (Vice Treasurer)
- Dr Lamourdia Thiombiano (Ex-Officio)
- Dr. Vincent Aduramigba-Modupe (Auditor)
- Dr Boubakar Likiby (Auditor)

The position of the Vice President is reserved for the host country of the next Conference.

For further information, please visit:

http://www.asssonline.org/

ISRIC

ISRIC is an independent foundation and the International Council for Science accredited World Data Centre for Soils. It was founded in 1964 through the International Soil Science Society (IUSS) and United Nations Educational, Scientific and Cultural Organization (UNESCO). It is supported by the Netherlands government and through grants for global soil programmes. It has a mandate to serve the international community as custodian of world soil data and information, and to increase awareness and understanding of soils in major global issues. ISRIC collects, stores, processes and disseminates global soil and terrain information for the research and development of sustainable land use. ISRIC operates in three priority areas, 1) soil data and soil mapping, 2) application of soil data in global development issues, and 3) training and education.

The soil databases of ISRIC have been compiled over the past decades by collaborating with partner institutes. They include primary global, regional and national data, including point data and maps as in WISE and SOTER (see pages 63 and 139). The information are being compiled into one database referred to as "World Soil Information Services". Current efforts of data collection and harmonisation are expected to lead to rapid expansion of this as ISRIC is simultaneously improving its services through web-based Global Soil Information Facilities (GSIF) to:

i) facilitate crowd-sourced, web-based entry, storage and extraction of soil profile data, area-class soil maps and global grids of environmental data, such as satellite imagery, digital elevation maps and climate and land cover maps;

ii) support the automated production of consistent, harmonised soil maps at multiple spatial scales;

iii) strengthen soil information handling capacity in an interactive and participatory process;

iv) provide feedback mechanisms to increase accuracy and user engagement; and

v) provide added-value products and processing chains to local, national, regional and global soil science communities.

Gradually, these components of GSIF are being made available and may be used by institutes throughout the world, linking scientists and institutes in a range of soil-related disciplines.

The relevance of high quality soil information is evident in global development issues related to soil and water management, soil carbon dynamics and soil degradation and rehabilitation. ISRIC makes a contribution to these issues by participating in global consortia. Improving soil and water conservation upstream results in increased agricultural productivity and reduced erosion, but is often not economically viable at the farm level. Off-farm benefits, such as reduced sedimentation in reservoirs with consequently increased hydropower production and increased water availability to urban areas, can be used to develop a funding mechanism involving downstream beneficiaries of upstream interventions to a sustainable implementation of soil and water conservation. ISRIC also contributes to the development of standardised systems to measure, model, monitor and forecast carbon stock changes and greenhouse gas emissions through sustainable land management projects (e.g. the web-based "Carbon Benefit Project" toolbox). Finally, ISRIC is advancing its methodologies to assess global land degradation by linking remote sensing methods to soil characteristics through crop growth simulation models.

On-the-ground verification and identification of intervention measures for mitigating and remediating degradation is obtained from research based on the global database on World Conservation Approaches and Technologies.

ISRIC maintains a world soil reference collection that includes over 1,000 soil profiles that have been described, sampled and analysed according to standard international methods. The collection is used for verifying national datasets, compiling global soil databases, comparing different methods of reference sample analysis, and for developing rules for soil property estimation. ISRIC continues to collect samples and monoliths; these are described, analysed and classified (following the World Reference Base) in relation to thematic issues including land degradation, climate change and biodiversity and prepared for display in the ISRIC – World Soil Museum in Wageningen. To increase access to its reference collection, to more effectively inform the general public and to educate an increasing number of students, ISRIC is digitising its monolith collection, making its publications and maps available online through the World Soil Library, and is investing in an innovative World Soil Museum. All these facilities are being tuned to optimise educational efforts by attracting more visitors and by seconding ISRIC staff to universities, primarily Wageningen, for teaching. A package of courses related to the activities of ISRIC can be tailor made for teaching specific groups. Students from all over the world are supervised by ISRIC staff and scientists are encouraged to visit ISRIC for enhanced collaboration.

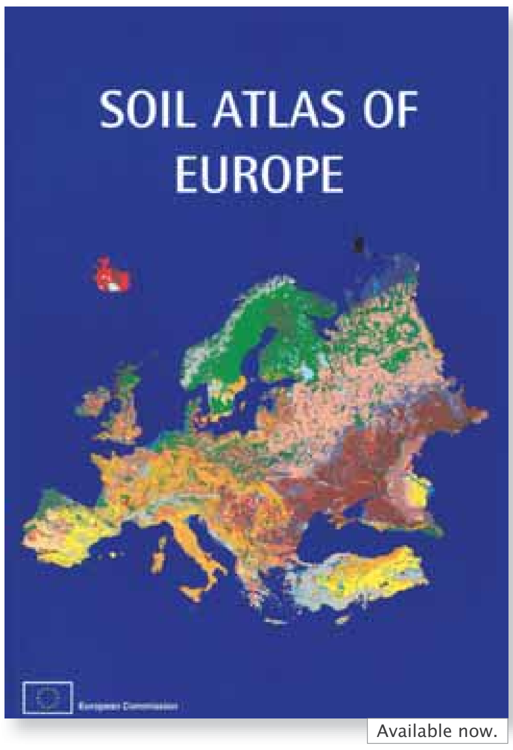
For further information, please visit:

http://www.isric.org

ISRIC World Soil Information
Droevendaalsesteeg 3,
6708 PB Wageningen
The Netherlands

JRC Soil Atlas Series

The European Commission's Joint Research Centre collaborates with soil scientists and researchers from all over the world to develop a series of soil-related atlases. To obtain a copy or for further information, please consult the Publications Office of the European Union (**http://publications.europa.eu/**) or the JRC SOIL Action's website (**http://eusoils.jrc.ec.europa.eu**).



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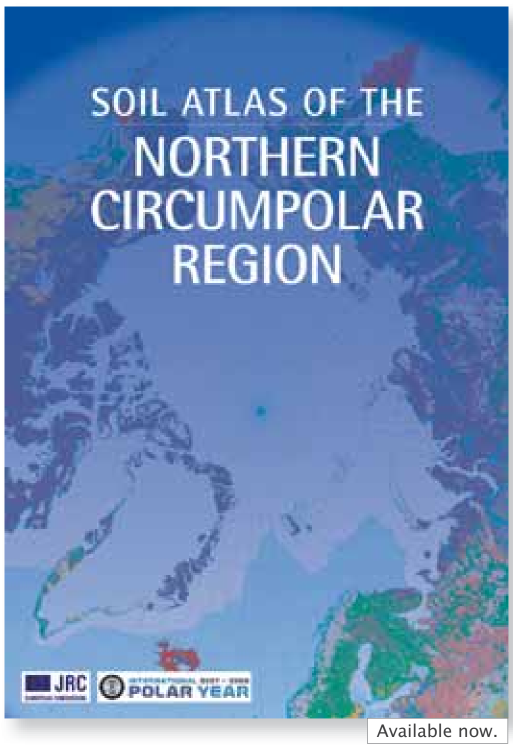

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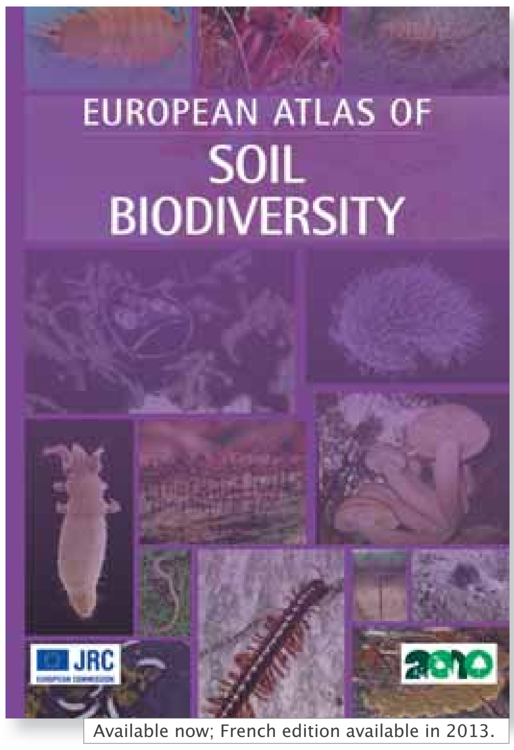
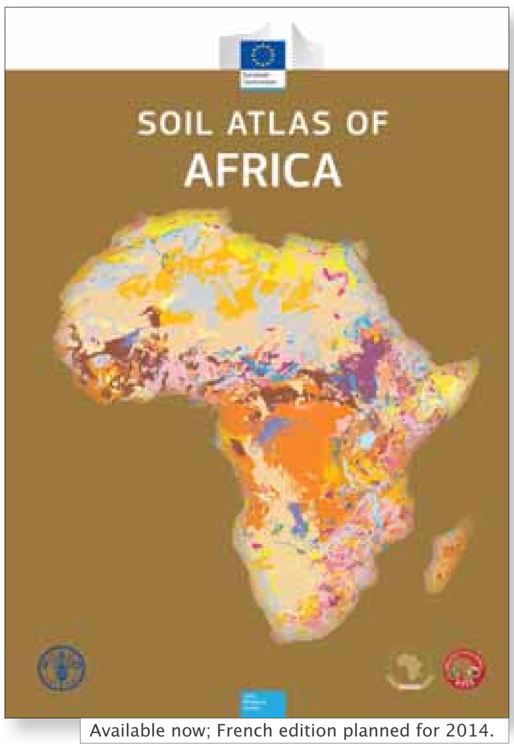
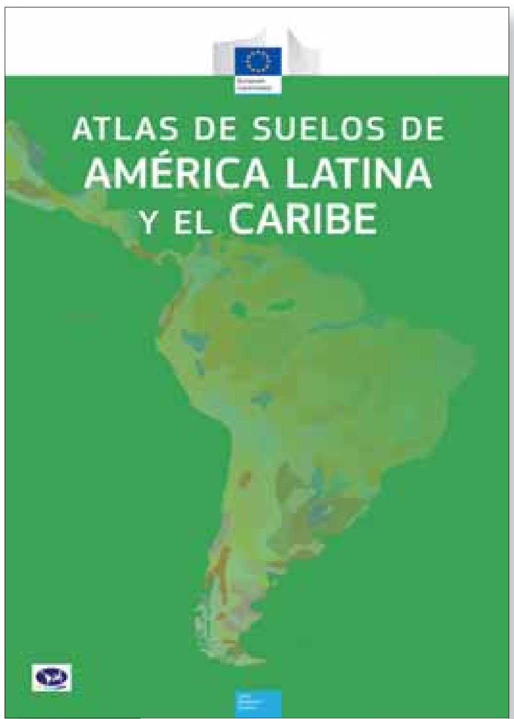


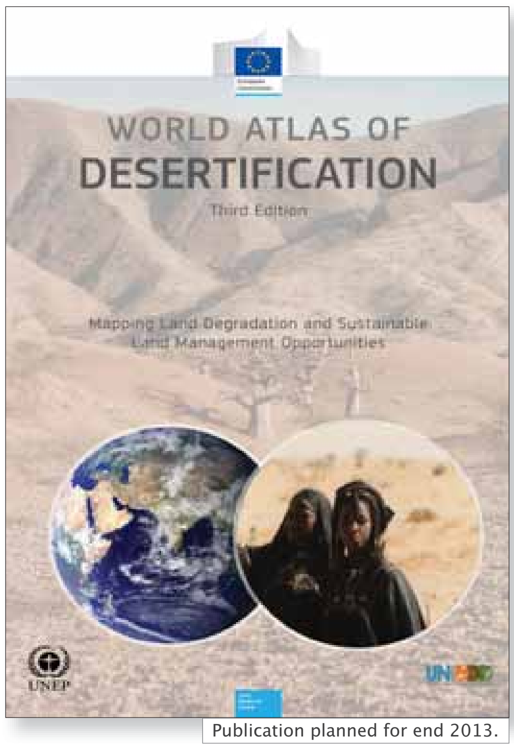
Available now; French edition available in 2013.



Available now; French edition planned for 2014.



Publication planned for 2013; Portuguese and English editions planned for 2014.



Publication planned for end 2013.

Publications Office of the European Union

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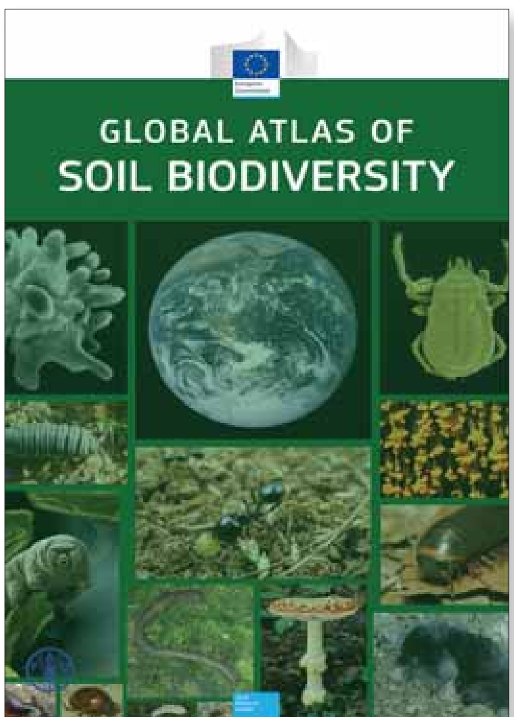
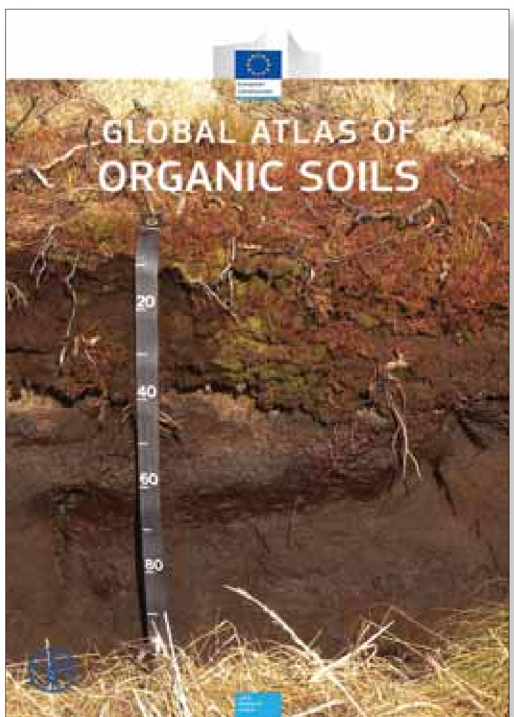
You can find publications through simple and advanced search functions (e.g. soil atlas), browsing by thematic area or by author (e.g. European Union institution). Furthermore, you may choose to sign up to 'My EU Bookshop' and access personalised functions, for example, save search queries for regular use, or be notified by e-mail about new releases that interest you.

The Publications Office aims to make the EU Bookshop the common entry point for European Union publications. Currently, the website is available in 22 languages. All soil atlases are available in hardcopy (€25) or as a pdf file (free of charge).



Under development.



Under development.

LB-NA-25534-EN-C

What is soil? Where does soil come from? What is special about soil in Africa? What does soil provide to society and the environment? How do our activities affect soil?

The first ever SOIL ATLAS OF AFRICA uses striking maps, informative texts and stunning photographs to answer and explain these and other questions.

Leading soil scientists from Europe and Africa have collaborated to produce this unique document. Using state of the art computer mapping techniques, the SOIL ATLAS OF AFRICA shows the changing nature of soil across the continent.

The SOIL ATLAS OF AFRICA explains the origin and functions of soil, describes the different soil types that can be found in Africa and their relevance to both local and global issues. The atlas also discusses the principal threats to soil and the steps being taken to protect soil resources.

The SOIL ATLAS OF AFRICA is more than just a normal atlas. Rather, this volume presents an interpretation of an often neglected natural resource that surrounds and affects us all.

The SOIL ATLAS OF AFRICA is an essential reference to a non-renewable resource that is fundamental for life on this planet.

Soils are a reflection of their parent material, climate, topography, vegetation, time and the influence of human activity. Their properties or characteristics are derived from the inter-play between these factors. The above photographs (from left to right) show an excavated termite mound in a Ferralsol in the Democratic Republic of the Congo (deeply weathered, iron-rich soil); a coffee ceremony in Northern Ethiopia - coffee plants thrive on deep, fertile, preferably volcanic soils; a lime-rich Calcisol from Morocco; students in Zimbabwe investigating the characteristics of Nitisols; a Stagnosol from South Africa (affected by water saturation). (EVR/KV/EM)

The properties of soil vary tremendously from region to region. Soils under tropical rainforests are vulnerable to erosion and nutrient depletion if the vegetation cover is removed. Oasis regions in deserts and the Sahel show how seemingly infertile soils can be cultivated in the presence of water. The wetlands of Congo and other major African systems are stores of soil organic carbon and important wildlife habitats. The black, clay-rich soils of the Nile Valley in Sudan are rich in nutrients but difficult to cultivate when very wet or very dry. Soils with high salt levels are not suitable for the cultivation of crops but may support a unique plant community.

Plants are dependent on soil for the supply of water, nutrients and as a medium for growing. Soil stores, filters, buffers and transforms substances that are introduced into the environment. This capability is crucial in producing and protecting water supplies and for regulating greenhouse gases. Soil is a provider of raw materials. Soil is also an incredible habitat and gene pool. Soil is a fundamental component of our landscape and cultural heritage.

Many traditional farming practices, such as the zai method from the Sahel, have been shown to improve soil quality and productivity while reducing soil losses. The photograph on the left shows a young sorghum crop being grown in land previously classified as degraded in Burkina Faso. Soil degradation is a major issue across large parts of Africa which, in turn, can affect food security, economic development and social cohesion. (RZ)

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